UNIVERSITY COLLEGE OF CAPE BRETON

Calibration of the N.C.B.Cone Indenter for the Sydney Coalfield Strata.

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DSS FILE NO.27ST. 23440-5-9010
Contract No.0ST85-00009

MICROMEDIA
JUL 18 1986

Submitted to
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Date Oct/85

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55 pp

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Calibration of the N.C.B. Cone Indenter to Traditional Uniaxial Compressive Strengths of Carboniferous Strata in the Sydney Coalfield.

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by
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and
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SUMMARY

The N.C.B. cone indenter, fashioned after the Rockwell hardness tester, is a hand held, easy to operate rock testing device which gives values that are correlatable to other physical characteristics of the material being tested.It is the primary objective of this work to determine the relationships which will equate the cone indenter (c.i.) values with the uniaxial compressive strengths (u.c.s) of the rocks of the Sydney Coalfield.

The N.C.B. cone indenter has been in use in the British coalfields since 1966 and their calibration factors are documented in the cone indenter handbook (ref. 1). However, when used to test rock of the Sydney Coalfield the British calibration factors give questionable results and this necessitates the recalibration of the insturment for the Sydney Coalfield.

The best relationships found from this experimentation equating cone indenter values to uniaxial compressive strength for the Sydney Coalfield strata are....

Y=37.7X-38.2 (y=u.c.s. x= mean c.i. value)
or Y=38.3X-36.2 (y=u.c.s. x= median c.i.value)

Our second objective was to measure any significant difference between cone indenter values obtained from compression tested debris and those values obtained from adjacent untested offcut core.The reason for this being that if there is a significant difference between compressed and uncompressed samples, machine-cut samples which have undergone compression during extraction, would have to be adjusted by some factor to get an in-situ cone indenter value and thus an in-situ compressive strength.

This experimentation has found no significant difference in values obtained from either offcuts or compressed debris.

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L'etalonnage de l' N.C.B. Indenteur conique aux Resistances a Ecrasements Uniaxial Traditionelles de le gîte Carbonifere de la région Carbonifere de Sydney.

par
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et
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Le Resume'

Le N.C.B. indenteur conique, faconne d'après le vérificateur de la duréte de Rockwell est un appareil portatif, facile a fonctionner en épreuvant les roches et qui donne les valeurs qui sont corrélatives aux autres caractéristiques physiques de la matière était verifiée. L'objectif fondamental de ce travail est à determiner les rapports qui établiront les valeurs de <l indenteur conique> avec celles des resistances a ecrasement <uniaxial> des roches de la région carbonifère de Sydney.

<L indenteur conique N.C.B.> a été en usage aux régions carbonifères Britainiques depuis dix-neuf cent soixante-six (1966) et leur facteurs d'etalonnage sont documentés dans la brochure de <l'indenteur conique>. Cependant en utilizant cet instrument à éprouver les roches de la région carbonifère de Sydney, les facteurs d'etalonnage Britannique donnent les resultats contestables et ceci le rend necessaire de retalonner cet appareil pour la région carbonifère de Sydney.

Les meilleurs connexites trouvée de cet expérimentation en égalisant les valeurs de <l'indenteur conique> a'la résistance à' écrasement <d'uniaxial> pour le gîte de la région carbonifere de Sydney sont les suivants.

Y=37.7X-38.2 (y=u.c.s x= moyenne c.i. valeur)
ou Y=38.3X-36.2 (y=u.c.s x= median c.i. valeur)

Notre objectif duexième était à' mesurer aucune différence significative entre les valeurs de <l'indenteur conique> obtenues des detritus surpressés mises à l'epreuve et ces valeurs obtenues <du coeur non-éprouvé decoupé contique>. La raison pour la quelle il était comme ceci est si il y a une différence significative entre les prélèvements sernés et non-sernés, les prélèvements coupés à' la machine dont ont subi la compression pendant l'extraction, devraient etre ajustés par un tel facteur à' rendre une valeur de l'indenteur conique <en-situ> et ausi, une resistance à' écrasement <en-situ>.

Cet expérimentation n'a trouvé aucune différence

significative en les valeurs obtenues d'un et l'autre découpure au détritus surpressés.

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TABLE OF CONTENTS
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	page
SUMMARY	I
RESUME	II
1. INTRODUCTION	1
2. LABORATORY TESTING	2
2.1 Programme Description	2
2.2 Specimen/Sample Selection and Preparation	2
2.3 Uniaxial Compression Testing	3
2.3.1 Machine Calibration	3
2.3.2 Testing Procedure	3
2.4 The NCB Cone Indenter	3
2.4.1 Calibration and Maintenance	4
2.4.2 Testing Procedure	4
2.5 Grain Size Analysis	4
3. RESULTS	5
3.1 Data Reduction	5
3.2 Compression Testing and Indenter Testing Results	6
3.3 I(w) Testing	7
4. DISCUSSION	8
4.1 Comparison of Offcuts and Compressed Specimens	8
4.2 Comparison of Lithological Types	8
4.3 Derivation of Calibration Equations	9
4.4 Effect of Specimen Size	10
4.5 Effect of Heterogeneity	10
4.6 I(w) Testing	10
5.CONCLUSIONS	11
6.RECOMMENDATIONS	11
7.ACKNOWLEDGEMENTS	12
8.REFERENCES	13
tables	
1. Samples and Locations	14
2. Raw Data for Scatter Plots	16
3. Comparative Table for Offcut and Compression Tested samples	17
4. I(w) Test Results	19
5. Table of Calibration Equations	20
figures	
1. Location Map	21
2. The NCB Cone Indenter	22
3,4 Calibration Graphs for the Compression Testing Machine	23
5-30 Scatter Plots of Calibration Equations	25-50

1. INTRODUCTION

A fundamental requirement of strata control/support design in coal mines is a knowledge of the mechanical properties of the host rock. This is conventionally obtained by the testing of core samples or more expensive and complex in-situ testing. In coal mining it is usually difficult to obtain core samples due to the expense and production delays often associated with core drilling, hence the development of property indices which when calibrated to traditional mechanical properties are less intrusive methods of obtaining basic information on strata properties. One such index testing device is the NCB Cone Indenter. This is a hand held ,easy to operate rock testing device which can give reliable rock strength data in minutes without any special sample preparation . A hardful of small rock chips is sufficient for indentation testing.

In order to provide the strata control/support design engineer with accurate information, the NCB Cone Indenter must be calibrated. A calibration for coal measures strata in the U.K. currently exists, but work by the Cape Breton Development Corporation (CBDC) indicates that this is not applicable to the carboniferous strata of the Sydney Coalfield. (figure 1 ,Pp 21). It is the primary objective of this contract to determine new calibration factors for the Sydney Coalfield.

The second important aspect of this contract is to determine whether or not cone indenter specimens which have undergone compressive stresses (machine cuttings) give different cone indenter values than specimens which have not been subjected to compression (in-situ specimens). The importance of this is that since in many instances cone indenter specimens will come from machine-cut debris there must be correction factors to yeild in-situ values.

2. LABORATORY TESTING

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2.1 PROGRAMME DESCRIPTION

Core samples were obtained from CBDC through CBCRL in Sydney. The cores were of the various rock types that make up the Carboniferous strata of the Sydney Coalfield. (table 1, Pp14). These samples were prepared for uniaxial compression testing and tested at ASTM standards on a calibrated load frame.

Index testing was then performed using the NCB Cone Indenter on specimens of offcut cores and debris from the compression tests. All samples were then bagged, labeled and returned to the CBCRL in Sydney.

Calibration factors/equations were then derived by computerized statistical analysis for the complete data, individual rock types, core offcuts, and compressed debris. Each of these types of equations were derived using mean cone indenter values and then again using median values. (table 2 ,Pp 16).

2.2 SPECIMEN/SAMPLE SELECTION AND PREPARATION

Selected core samples were cut at a length to diameter ratio of 2 to 1 using an 18" diamond blade rotary rock saw. The feed mechanism on the saw insures that the cores are cut with parallel ends and that the ends are perpendicular to the core's longitudinal axis. Some cores were cut at ratios other than 2:1 and in these cases Hobb's formula, as stated in the cone indenter handbook, was used to adjust the u.c.s. values to 2:1. From this procedure a u.c.s. sample and an adjacent offcut sample were obtained. These samples were labeled and bagged along with their respective data sheets.

After the cores were broken in the compression machine the debris was crushed in a small jaw crusher to -3/8". The offcut pieces of core were reduced to -3/8" using a mall and bucking board. This particular size reduction procedure for the offcuts was by instruction from the Scientific Authority. The 3/8" size specimens were found to be the best size for cone indentation. Smooth tabular specimens were used for indentation rather than rough irregular specimens because the smooth specimens gave more consistent results.

2.3 UNIAXIAL COMPRESSION TESTING.

2.3.1. MACHINE CALIBRATION

Prior to testing, the universal testing machine was calibrated by the Mechanical Technology department at U.C.C.B. using a proving ring. The calibration graphs (figure 3,4 ,Pp23) were used to adjust all measurements made thereafter.

2.3.2. TESTING PROCEDURE

Prepared cores were centered on the loading platform of the testing machine and stressed to failure at a stress rate between 0.5 Mpa/s and 1.0 Mpa/s as stated in the CANMET Lab Manual (reference #4).The reading at failure was recorded on the sample data sheet and adjusted according to the calibration graphs .The debris along with the data sheets were than re-bagged for crushing.

2.4 THE N.C.B.CONE INDENTER.

There has long been a need for a portable instrument capable of giving a measure of rock strength without requiring the preparation of accurately shaped and finished specimens.Such an instrument known as the Cone Indenter is now available to fill that need.

The instrument (figure 2,Pp 22)which works on a similar principal to that employed in metallurgical hardness testers, is designed to determine the hardness of rock by measuring its resistance to indentation by a hardened tungsten carbide cone.

It comprises a portal steel frame in which a steel strip is clamped along a longitudinal axis. At one side of the instrument a dial guage is set up so that its probe is in contact with one side of the steel strip.In the middle of the other side of the instrument a micrometer with a hollow spindle housing a tungsten carbide tip is fitted.The flat base of the tip is seated on a steel ball which allows the tip to rotate in its housing.

The cone indenter hardness value for any particular test is obtained by dividing the force (i.e. spring deflection) necessary to cause penetration by the amount of penetration that has occurred. Thus cone indenter number is

$$I = \frac{D}{P}$$

where D= steel strip deflection (.66MM which is 40 newtons-Is)
and P= penetration.(MM)

2.4.1 CALIBRATION AND MAINTENANCE

On a weekly basis the cone indenter was tested under a 40 newton load (Is-standard cone indenter number) to verify the dial guage reading for that load.The dial guage reading was .66mm for all our testing.

The tungsten carbide tips were also checked for wear under the microscope at this time and replaced when necessary.

2.4.2 TESTING PROCEDURE

Smooth tabular specimens, not greater than 3/8" were selected for indentation and placed on the steel strip of the indenter. The indenter micrometer screw was turned just enough to hold the specimen in place on the steel strip. The dial guage was then set to zero and the micrometer screw read (M0). The micrometer screw was then turned until the dial guage read .66 (D1-40 newtons) and the second micrometer reading was taken as (M1). Penetration of the cone into the specimen is then given by

$$P = (M1-M0)-D1.$$

and finally the standard cone indenter number was given by

$$I = \frac{D1}{P}$$

2.5 GRAIN SIZE ANALYSIS.

As a check on sample nomenclature, grain sizes were measured under the microscope and the following is a list of grain size ranges for the various rock types.

Coarse Sandstone	----------	.3 to .5mm
Medium Sandstone	----------	.1 to .3mm
Fine Sandstone	----------	.05 to .1mm
Siltstone	----------	.01 to .05mm
Mudstone	----------	.01 to .00mm

* please note that there is some overlap between consecutive size ranges.

3. RESULTS
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3.1 DATA REDUCTION

Our data which is made up of uniaxial compressive strengths (u.c.s. values) and standard cone indenter numbers (Is values) required some processing before values could be paired for regression analysis.

First, compressive strengths were corrected according to the calibration charts at the back of this report. Then the compressive strengths were adjusted to the same length to diameter ratio using Hobb's formula as stated in the Cone Indenter Handbook (reference # 1).Finally the compressive strengths were converted from Imperial values (lbf/in) to Metric values (Mpa).

For the most part the only data reduction required for the cone indenter values was to find the mean of the number of cone indenter values taken (usually 50 cases). It was realized rather late in this experimentation that due to the heterogenious nature of some core material median values could be more important to use for regression analysis and therefore two types of calibration equations were derived - one using the mean Is value and the other using the median Is value. Means, medians and frequency distributions of the cone indenter values were obtained by computer statistical analysis (reference # 7) at UCCB.

The reduced data was then tabulated as shown in table 2,Pp 16 and also on Pp 6.

3.2 COMPRESSION TESTING AND INDENTER TESTING RESULTS

The following table lists the reduced results and subsequently all equations are derived from paired data from this list.

UCCB SAMPLE NO	ROCK TYPE	COMPRESSIVE STRENGTH(Mpa)	CONE INDENTER VALUES (MEANS)		(MEDIANS)	
			COMPRESSED	OFFCUT	COMPRESSED	OFFCUT
136	Ss(c)	39.0	2.2649	2.3146	2.2540	2.2540
114	Ss(c)	40.0	2.6131	2.5355	2.5330	2.2540
115	Ss(c)	42.8	2.3136	2.2711	2.2540	2.1810
127	Ss(c)	56.0	2.7608	2.7892	2.5330	2.5840
116	Ss(c)	46.2	2.2414	2.2518	2.1625	2.1985
102	Ss(m)	60.0	2.5792	2.5276	2.5350	2.4400
104	Ss(m)	60.0	2.5898	2.4892	2.4400	2.4860
105	Ss(m)	71.5	2.8244	2.7042	2.6440	2.5580
106	Ss(m)	61.7	2.6488	2.5755	2.5580	2.5090
126	Ss(f)	79.7	2.7729	2.8955	2.5090	2.8300
125	Ss(f)	74.8	2.7622	2.8429	2.8300	2.8000
124	Ss(f)	83.5	2.8851	2.8005	2.8005	2.8300
101	Ss(f)	50.3	2.6998	2.7834	2.7420	2.7750
100	Ss(f)	72.5	2.9332	2.9934	2.7420	2.7710
110	Siltstone	94.0	3.3054	3.2906	3.1670	3.2290
109	Siltstone	55.5	2.6515	2.6964	2.5580	2.5580
108	Siltstone	59.4	3.0971	2.9661	2.8725	2.9560
107	Siltstone	103.0	2.8288	2.9587	2.6340	2.8600
103	Siltstone	33.9	2.1107	2.0379	2.1180	2.0245
123	Mudstone	25.7	1.8026	1.8448	1.7500	1.7730
122	Mudstone	31.8	1.8127	1.8182	1.6945	1.7270
121	Mudstone	25.7	1.8716	1.8780	1.7270	1.7970
120	Mudstone	33.3	1.8484	1.9009	1.7500	1.8650
118	Mudstone	33.7	1.3576	1.3419	1.3105	1.2875
113	Mudstone	33.9	1.8829	1.9451	1.7730	1.8470
111	Mudstone	33.5	1.9418	2.0206	1.8470	1.8870

3.3 I(w) TESTING.

In the early stages of this contract some testing was performed at a lower force than standard for reasons which are explained in section 4.6 of this report. This lower force is 12 newtons for the I(w) tests and the results are as follows.

Table 4

COMPARISON OF CONE INDENTER VALUES FOR OFFCUT AND COMPRESSION TESTED SAMPLES SHOWING EXPERIMENTAL ERROR (PERCENTAGE DIFFERENCE)

****

(ALL TESTS PERFORMED @ 12 N - (Iw))

UCCB SAMPLE NO.	CEDC SAMPLE NO.	CONE INDERTER VALUE (ARITHMETIC MEAN) COMPRESSED (A)	OFFCUTS (B)	PERCENTAGE DIFFERENCE (A-B)/A*100 (C)
102	3	3.18192	3.23886	-1.78949%
107	19	2.89942	2.80702	+3.18684%
106	4	3.43390	3.52504	-2.65413%
104	4	3.36866	3.34568	+0.68217%

4. DISCUSSION

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4.1 COMPARISON OF OFFCUTS AND COMPRESSED SPECIMENS

Our comparative analysis of offcut and compressed specimen cone indenter values (table 3,Pp17) does not show any consistantly reliable difference between the two types of specimens. Allowing for a 5% experimental error during testing it can be seen that no percentages exceed this experimental error range. It should also be noted from this table that the algebraic signs of percentage differences are fairly well balanced.

4.2 COMPARISON OF LITHOLOGICAL TYPES

A brief study of table 2 reveals that the strongest rock types are the medium grained rocks, fine grained sandstone and siltstone, with the very coarse and the very fine grained rocks having lower cone indenter values. The reason for this was not addressed by this experimentation.

4.3 DERIVATION OF CALIBRATION FORMULAS

The following equations have been derived by computerized regression analysis of paired data from table 2 and the scatter plots of each equation are at the back of this report.

TABLE OF CALIBRATION FORMULAS

****

			formula	R
COMPRESSED	MEANS	1 COARSE SANDSTONE	>>> Mpa=13.0*C.I.+12.5	(.531)
		2 MEDIUM SANDSTONE	>>> Mpa=48.7*C.I.-66.4	(.992)
		3 FINE SANDSTONE	>>> Mpa=78.6*C.I.-148.6	(.582)
		4 SILTSTONE	>>> Mpa=43.9*C.I.-53.7	(.703)
		5 MUDSTONE	>>> Mpa=-3.7*C.I.+37.8	(-.196)
	MEDIANS	6 COARSE SANDSTONE	>>> Mpa=28.1*C.I.-18.2	(.794)
		7 MEDIUM SANDSTONE	>>> Mpa=56.0*C.I.-79.3	(.844)
		8 FINE SANDSTONE	>>> Mpa=-13.6*C.I.+109.2	(-.132)
		9 SILTSTONE	>>> Mpa=49.7*C.I.-63.5	(.675)
		10 MUDSTONE	>>> Mpa=-4.2*C.I.+38.1	(-.195)
OFFCUTS	MEANS	11 COARSE SANDSTONE	>>> Mpa=15.5*C.I.+6.5	(.619)
		12 MEDIUM SANDSTONE	>>> Mpa=57.4*C.I.-84.6	(.967)
		13 FINE SANDSTONE	>>> Mpa=43.7*C.I.-52.9	(.285)
		14 SILTSTONE	>>> Mpa=50.0*C.I.-70.3	(.820)
		15 MUDSTONE	>>> Mpa=-2.3*C.I.+35.3	(-.138)
	MEDIANS	16 COARSE SANDSTONE	>>> Mpa=27.1*C.I.-17.8	(.779)
		17 MEDIUM SANDSTONE	>>> Mpa=98.5*C.I.-182.9	(.869)
		18 FINE SANDSTONE	>>> Mpa=339.4*C.I.-878.6	(.748)
		19 SILTSTONE	>>> Mpa=49.5*C.I.-65.8	(.793)
		20 MUDSTONE	>>> Mpa=-2.9*C.I.+36.1	(-.160)
COMPRESSED	MEANS	21	>>>>>>>>>>>>>>>>>>> Mpa=37.1*C.I.-36.6	(.835)
	MEDIANS	22	>>>>>>>>>>>>>>>>>>> Mpa=37.5*C.I.-33.8	(.809)
OFFCUTS	MEANS	23	>>>>>>>>>>>>>>>>>>> Mpa=38.6*C.I.-40.4	(.855)
	MEDIANS	24	>>>>>>>>>>>>>>>>>>> Mpa=39.2*C.I.-38.5	(.866)
OVERALL	MEANS	25	>>>>>>>>>>>>>>>>>>> Mpa=37.7*C.I.-38.2	(.844)
	MEDIANS	26	>>>>>>>>>>>>>>>>>>> Mpa=38.3*C.I.-36.2	(.837)

*The numbers in brackets are correlation coefficents (R)

4.4 EFFECT OF SPECIMEN SIZE

During this experimentation an attempt was made to resolve all data tc a standard core diameter. When no mechanism for this standardizing process could be found in texts, after a rather thcrough library search, we tried to plot our own data to find a relationship between core diameter and uniaxial compressive strength but the range of core diameters used on any given rock type was too small for any reliable relationship to be found.

4.5 EFFECT OF HETEROGENEITY

Cone indenter values can be highly variable when testing samples containing siderite or pyrite. Histograms of these values are bimodal and the mean of the set of indenter values correlates poorly with uniaxial compressive strength. It is for this reason that the table of calibration formulas (Pp 20) gives both types of calibration formulas - one for means and the other for medians.

4.6 I(w) TESTING

In the early stages of this calibration contract we performed some testing or calibration work on the Iw (12 N load) scale.This was done to alleviate the difficulties we were experiencing with samples splitting in the indenter when under the Is (40 N) load.The Iw scale was the suggested cure in early editions of the N.C.B. Cone Indenter Handbook for samples that were splitting.Table 4 lists the data gathered from that work.

Shortly after our testing started using the Iw scale it was noted that newer editions of the N.C.B Handbook no longer suggested the use of the Iw scale and we don't know the reason for the omission.At that point test work on the Iw scale was stopped and we began using 3/8" size specimens because this slightly larger size worked very well eliminating the splitting problem without switching to a different scale.All remaining work was performed using 3/8" specimens under a 40 newton load.

Since this Iw data is so limited we can not draw many conclusions from it except that the Iw values can be very different from Is values of the same samples listed in table 3.

Iw cone indenter values were not used for deriving calibration equations.

5. CONCLUSIONS

Due to the high correlation coefficent values given to equations 25 and 26 in the table of calibration equations we conclude that the relationships stated by these formulas are valid.

Since we could not find any solid evidence to support the theory that a difference existed between offcut and compressed specimens (table 3,Pp17), equations 21 to 24 are redundant.

The extreme variability of correlation coefficents given by individual rock types, equations 1 to 20, suggests that these formulas are based on too few data points and should be abandoned.

6. RECOMMENDATIONS

Due to the sometimes highly variable nature of cone indenter values which can be given by some samples we would recommend that not less than 25 indentations be performed to obtain a mean or median value.This number could be reduced in time with operator experience.

We would not recommend the use of the formulas derived for individual rock types because they are based on too few data points.

The operator of the cone indenter must be wary of samples containing siderite or pyrite or other hard minerals which yield a high mean cone indenter value and in these cases use the median cone indenter value and median equation to obtain rock strength values.

Finally, it is important for the cone indenter operator to use smooth flat specimens in the indenter because rough irregular specimens yield high penetration values and thus low strength values.

7. ACKNOWLEDGEMENTS

The authors wish to thank the Cape Breton Coal Research Laboratory (EMR), for providing the opportunity to involve the students and staff of the Mineral Technology department of UCCB in this experimentation and we would also like to thank the other members of UCCB Mineral Technology staff who were not directly involved in the project but provided assistance during the contract.

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Table I
CORE SAMPLE DATA

UCCB NO	CBDC NO	ROCK TYPE	LOCATION
100	1	SANDSTONE(FINE)	HOLE 8392 BOX 5/10 70'9" - 73'2"
101	2	SANDSTONE(FINE)	HOLE 8392 BOX 5/10 76'4" - 77'4"
104,105, 106	4	SANDSTONE(MEDIUM)	HOLE C111 BOX 1 37'10" - 39'7"
111	11	MUDSTONE	HOLE C-130 BOX 8 181'2" - 181'8"
113	12	MUDSTONE	HOLE C-130 BOX 8 181'8" - 182'4"
120	13	MUDSTONE	HOLE C-130 BOX 8 182'4" - 182'11"
121	14	MUDSTONE	HOLE C-130 BOX 8 183'8" - 184'3"
122	15	MUDSTONE	HOLE C-130 BOX 8 184'3" - 184'9"
118	16	MUDSTONE	HOLE C-130 BOX 8 184'9" - 185'3"
103	17	SILTSTONE	HOLE A45 BOX 71 1108'0" - 1109'0"
109,110	18	SILTSTONE	HOLE A45 BOX 71 1109'0" - 1110'4"
107,108	19	SILTSTONE	HOLE A45 BOX 71 1110'4" - 1111'10"
125	20	SANDSTONE(FINE)	HOLE C-108 BOX 5 119'0" - 119'10"
124	21	SANDSTONE(FINE)	HOLE C-108 BOX 5 119'10" - 120'9"
126	24	SANDSTONE(FINE)	HOLE C-108 BOX 5 122'4" - 123'0"

Table 1 Cont.

UCCB NO	CBDC NO	ROCK TYPE	LOCATION
127	26	SANDSTONE(COARSE)	HOLE C-108 BOX 5 133'10" - 135'0"
123	29	MUDSTONE	BOREHOLE 8 BOX 4 # 2799.64
114	22	SANDSTONE(COARSE)	HOLE C-108 BOX 5 135'6" - 137'4"
102	3	SANDSTONE(MEDIUM)	HOLE C111 BOX 1 35'8" - 36'5"
136	9	SANDSTONE(COARSE)	HOLE 1 PRINCE 4W BOX 1 23'6"-24'1"
116	27	SANDSTONE(COARSE)	HOLE C-108 BOX 5 132'2" - 133'10"
115	23	SANDSTONE(COARSE)	HOLE C-108 BOX 5 131'4" - 132'2"

TABLE 2

RAW DATA FOR SCATTER PLOTS

UCCB SAMPLE NO	ROCK TYPE	COMPRESSIVE STRENGTH(Mpa)	CONE INDENTER VALUES (MEANS)		(MEDIANS)	
			COMPRESSED	OFFCUT	COMPRESSED	OFFCUT
136	Ss(c)	39.0	2.2649	2.3146	2.2540	2.2540
114	Ss(c)	40.0	2.6131	2.5355	2.5330	2.2540
115	Ss(c)	42.8	2.3136	2.2711	2.2540	2.1610
127	Ss(c)	56.0	2.7608	2.7892	2.5330	2.5840
116	Ss(c)	46.2	2.2414	2.2518	2.1625	2.1985
102	Ss(m)	60.0	2.5792	2.5276	2.5350	2.4400
104	Ss(m)	60.0	2.5698	2.4892	2.4400	2.4860
105	Ss(m)	71.5	2.8244	2.7042	2.6440	2.5580
106	Ss(m)	61.7	2.6488	2.5755	2.5580	2.5090
126	Ss(f)	79.7	2.7729	2.8955	2.5090	2.8300
125	Ss(f)	74.8	2.7622	2.8429	2.8300	2.8000
124	Ss(f)	83.5	2.8851	2.8005	2.8005	2.8300
101	Ss(f)	50.3	2.6998	2.7834	2.7420	2.7750
100	Ss(f)	72.5	2.9332	2.9934	2.7420	2.7710
110	Siltstone	94.0	3.3054	3.2906	3.1670	3.2290
109	Siltstone	55.5	2.6515	2.6964	2.5580	2.5580
108	Siltstone	59.4	3.0971	2.9661	2.8725	2.9560
107	Siltstone	103.0	2.8288	2.9587	2.6340	2.8600
103	Siltstone	33.9	2.1107	2.0379	2.1180	2.0245
123	Mudstone	25.7	1.8026	1.8448	1.7500	1.7730
122	Mudstone	31.8	1.8127	1.8182	1.6945	1.7270
121	Mudstone	25.7	1.8716	1.8780	1.7270	1.7970
120	Mudstone	33.3	1.8484	1.9009	1.7500	1.8650
118	Mudstone	33.7	1.3576	1.3419	1.3105	1.2875
113	Mudstone	33.9	1.8829	1.9451	1.7730	1.8470
111	Mudstone	33.5	1.9418	2.0206	1.8470	1.8870

Table 3

CONE INDENTER VALUES FOR OFFCUT AND
COMPRESSION TESTED SAMPLES SHOWING
EXPERIMENTAL ERROR (PERCENTAGE DIFFERENCE)
****
(ALL TESTS PERFORMED @ 40 N - (Is))

UCCB SAMPLE NO	CBDC SAMPLE NO	CONE INDENTER VALUE (ARITHMETIC MEAN) COMPRESSED (A)	OFFCUTS (B)	PERCENTAGE DIFFERENCE (A-B)/A*100 (C)
100	1	2.93320	2.99338	-2.05168%
101	2	2.69980	2.78344	-3.09801%
105	4	2.82440	2.70426	+4.25365%
* 111	11	1.94183	2.02060	-4.05648%
113	12	1.88294	1.94514	-3.30334%
120	13	1.84838	1.90088	-2.84033%
121	14	1.87162	1.87800	-0.34088%
* 122	15	1.81273	1.81823	-0.30340%
118	16	1.35758	1.34188	+1.15647%
103	17	2.11076	2.03792	+3.45089%
109	18	2.65154	2.69642	-1.69260%
110	18	3.30538	3.29062	+0.44654%
107	19	2.82888	2.95870	-4.58910%
108	19	3.09714	2.96608	+4.23165%
125	20	2.76218	2.84292	-2.92305%
124	21	2.88510	2.80054	+2.93092%
126	24	2.77298	2.89554	-4.41979%

* Based on 30 samples tested

Table 3 Cont.

CONE INDENTER VALUES FOR OFFCUT AND
COMPRESSION TESTED SAMPLES SHOWING
EXPERIMENTAL ERROR (PERCENTAGE DIFFERENCE)
****
(ALL TESTS PERFORMED @ 40 N - (Is))

UCCB SAMPLE NO	CBDC SAMPLE NO	CONE INDENTER VALUE (ARITHMETIC MEAN) COMPRESSED (A)	OFFCUTS (B)	PERCENTAGE DIFFERENCE (A-B)/A*100 (C)
* 127	26	2.76087	2.78920	-1.02613%
* 123	29	1.80260	1.84483	-2.34273%
* 114	22	2.61307	2.53553	+2.96739%
* 102	3	2.57920	2.52763	+1.99946%
* 104	4	2.58987	2.48920	+3.88707%
* 106	4	2.64887	2.57550	+2.76986%
* 136	9	2.26497	2.31460	-2.19120%
* 116	27	2.24147	2.25183	-0.46219%
* 115	23	2.31367	2.27110	+1.83993%

* Based on 30 samples tested

Table 4

CONE INDENTER VALUES FOR OFFCUT AND
COMPRESSION TESTED SAMPLES SHOWING
EXPERIMENTAL ERROR (PERCENTAGE DIFFERENCE)
****
(ALL TESTS PERFORMED @ 12 N - (Iw))

UCCB SAMPLE NO	CBDC SAMPLE NO	CONE INDENTER VALUE (ARITHMETIC MEAN) COMPRESSED (A)	OFFCUTS (B)	PERCENTAGE DIFFERENCE (A-B)/A*100 (C)
102	3	3.18192	3.23886	-1.78949%
107	19	2.89942	2.80702	+3.18684%
106	4	3.43390	3.52504	-2.65413%
104	4	3.36866	3.34568	+0.68217%

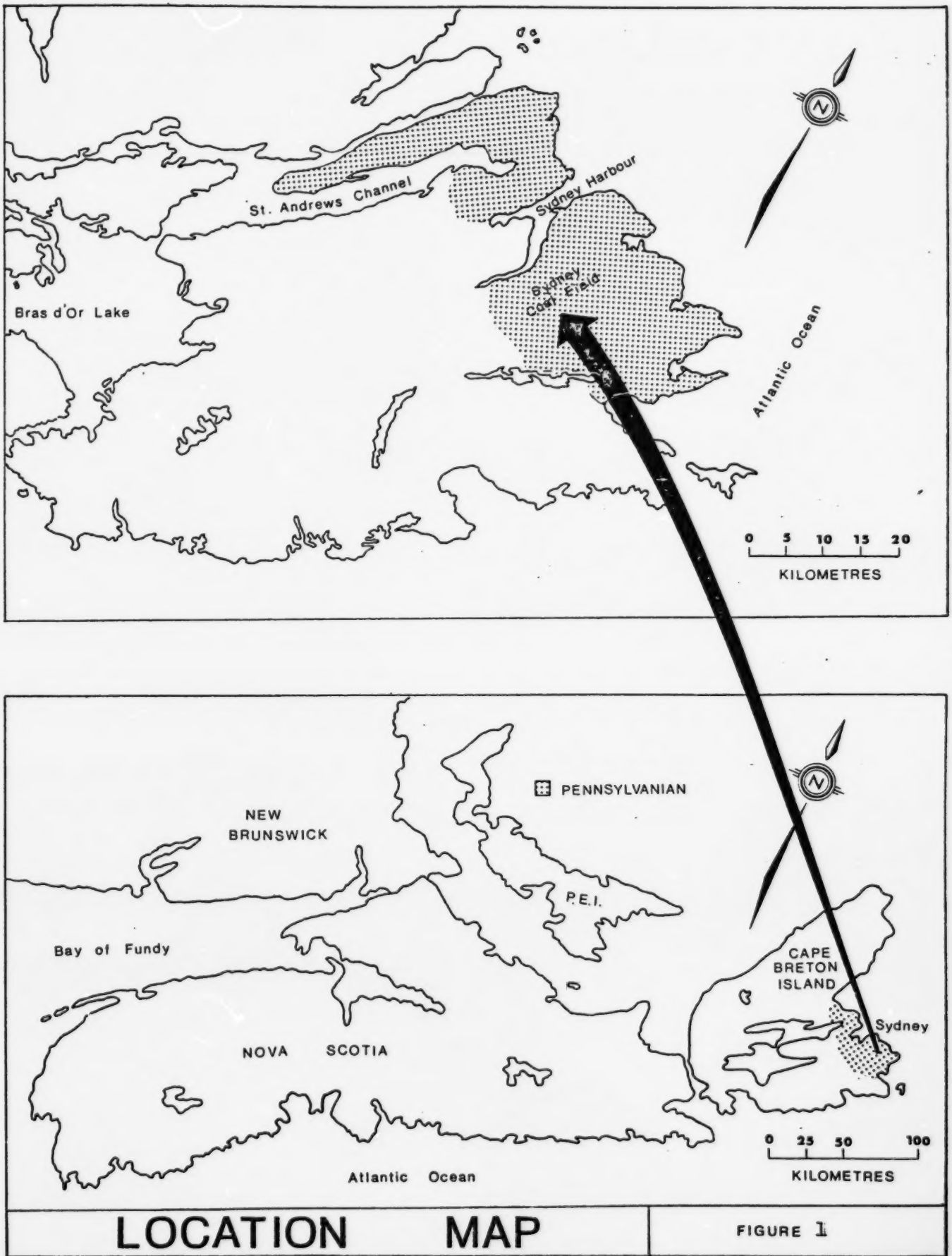
TABLE 5

TABLE OF CALIBRATION FORMULAS

****

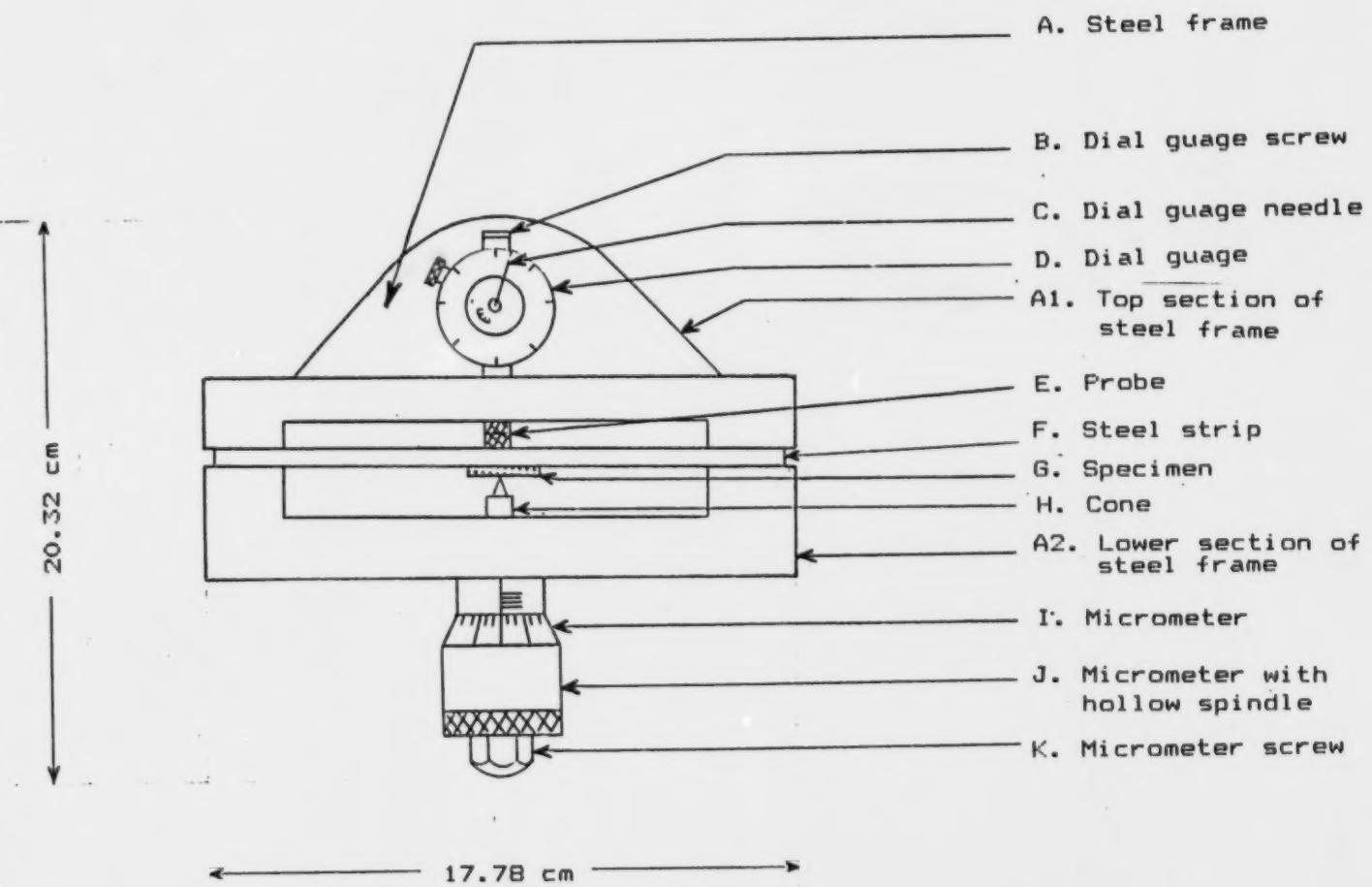
				formula	R
COMPRESSED	MEANS	1	COARSE SANDSTONE	>>> Mpa=13.0*C.I.+12.5	(.531)
		2	MEDIUM SANDSTONE	>>> Mpa=48.7*C.I.-66.4	(.992)
		3	FINE SANDSTONE	>>> Mpa=78.6*C.I.-148.6	(.582)
		4	SILTSTONE	>>> Mpa=43.9*C.I.-53.7	(.703)
		5	MUDSTONE	>>> Mpa=-3.7*C.I.+37.8	(-.196)
	MEDIANS	6	COARSE SANDSTONE	>>> Mpa=28.1*C.I.-18.2	(.794)
		7	MEDIUM SANDSTONE	>>> Mpa=56.0*C.I.-79.3	(.844)
		8	FINE SANDSTONE	>>> Mpa=-13.6*C.I.+109.2	(-.132)
		9	SILTSTONE	>>> Mpa=49.7*C.I.-63.5	(.675)
		10	MUDSTONE	>>> Mpa=-4.2*C.I.+38.1	(-.195)
OFFCUTS	MEANS	11	COARSE SANDSTONE	>>> Mpa=15.5*C.I.+6.5	(.619)
		12	MEDIUM SANDSTONE	>>> Mpa=57.4*C.I.-84.6	(.967)
		13	FINE SANDSTONE	>>> Mpa=43.7*C.I.-52.9	(.285)
		14	SILTSTONE	>>> Mpa=50.0*C.I.-70.3	(.820)
		15	MUDSTONE	>>> Mpa=-2.3*C.I.+35.3	(-.138)
	MEDIANS	16	COARSE SANDSTONE	>>> Mpa=27.1*C.I.-17.8	(.779)
		17	MEDIUM SANDSTONE	>>> Mpa=98.5*C.I.-182.9	(.869)
		18	FINE SANDSTONE	>>> Mpa=339.4*C.I.-878.6	(.748)
		19	SILTSTONE	>>> Mpa=49.5*C.I.-65.8	(.793)
		20	MUDSTONE	>>> Mpa=-2.9*C.I.+36.1	(-.160)
COMPRESSED	MEANS	21		>>>>>>>>>>>>>>>>>>> Mpa=37.1*C.I.-36.6	(.835)
	MEDIANS	22		>>>>>>>>>>>>>>>>>>> Mpa=37.5*C.I.-33.8	(.809)
OFFCUTS	MEANS	23		>>>>>>>>>>>>>>>>>>> Mpa=38.6*C.I.-40.4	(.855)
	MEDIANS	24		>>>>>>>>>>>>>>>>>>> Mpa=39.2*C.I.-38.5	(.866)
OVERALL	MEANS	25		>>>>>>>>>>>>>>>>>>> Mpa=37.7*C.I.-38.2	(.844)
	MEDIANS	26		>>>>>>>>>>>>>>>>>>> Mpa=38.3*C.I.-36.2	(.837)

*The numbers in brackets are correlation coefficents (R)



LOCATION MAP

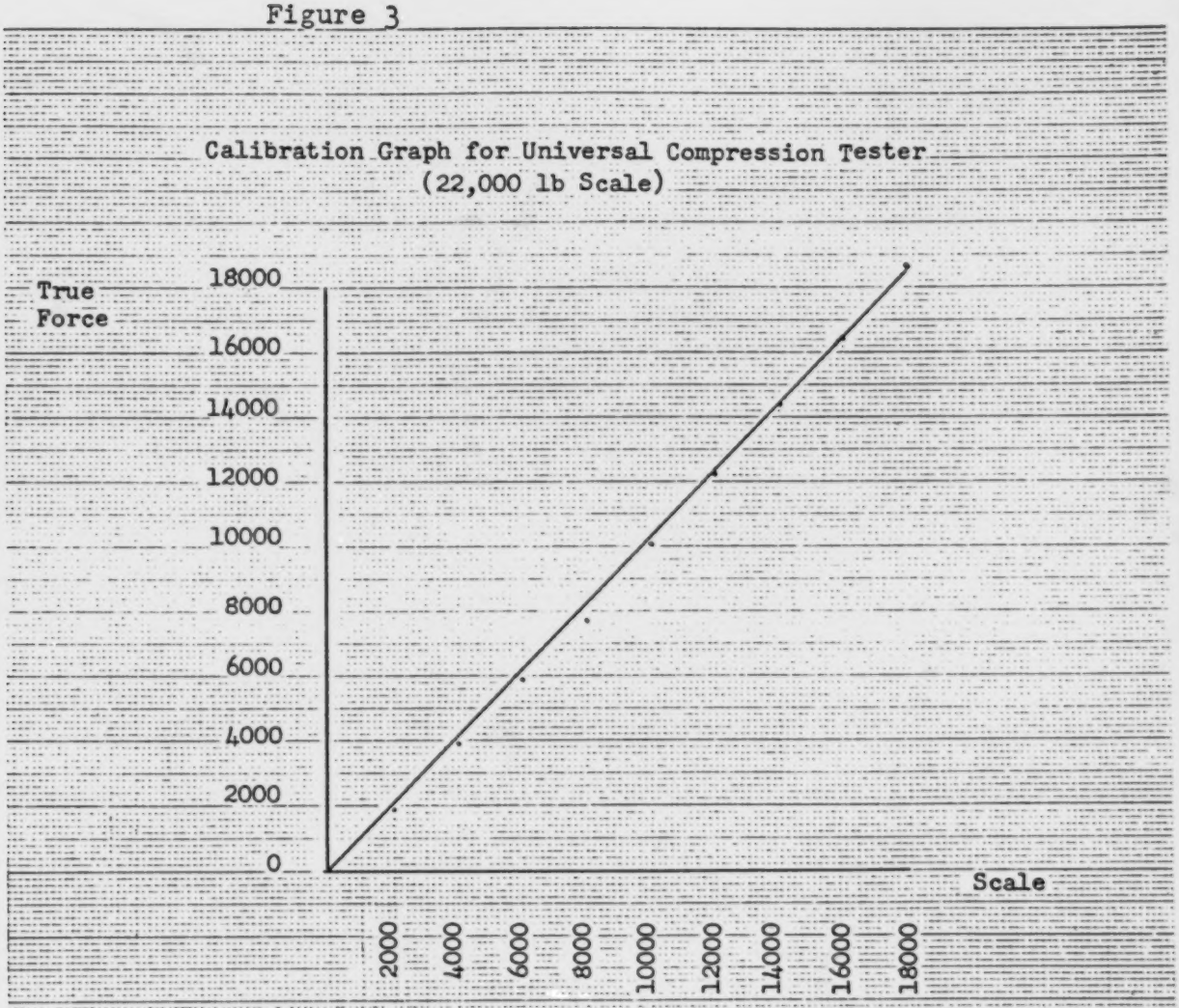
FIGURE 1



COMPONENTS OF THE NCB CONE INDENTER

Figure 2

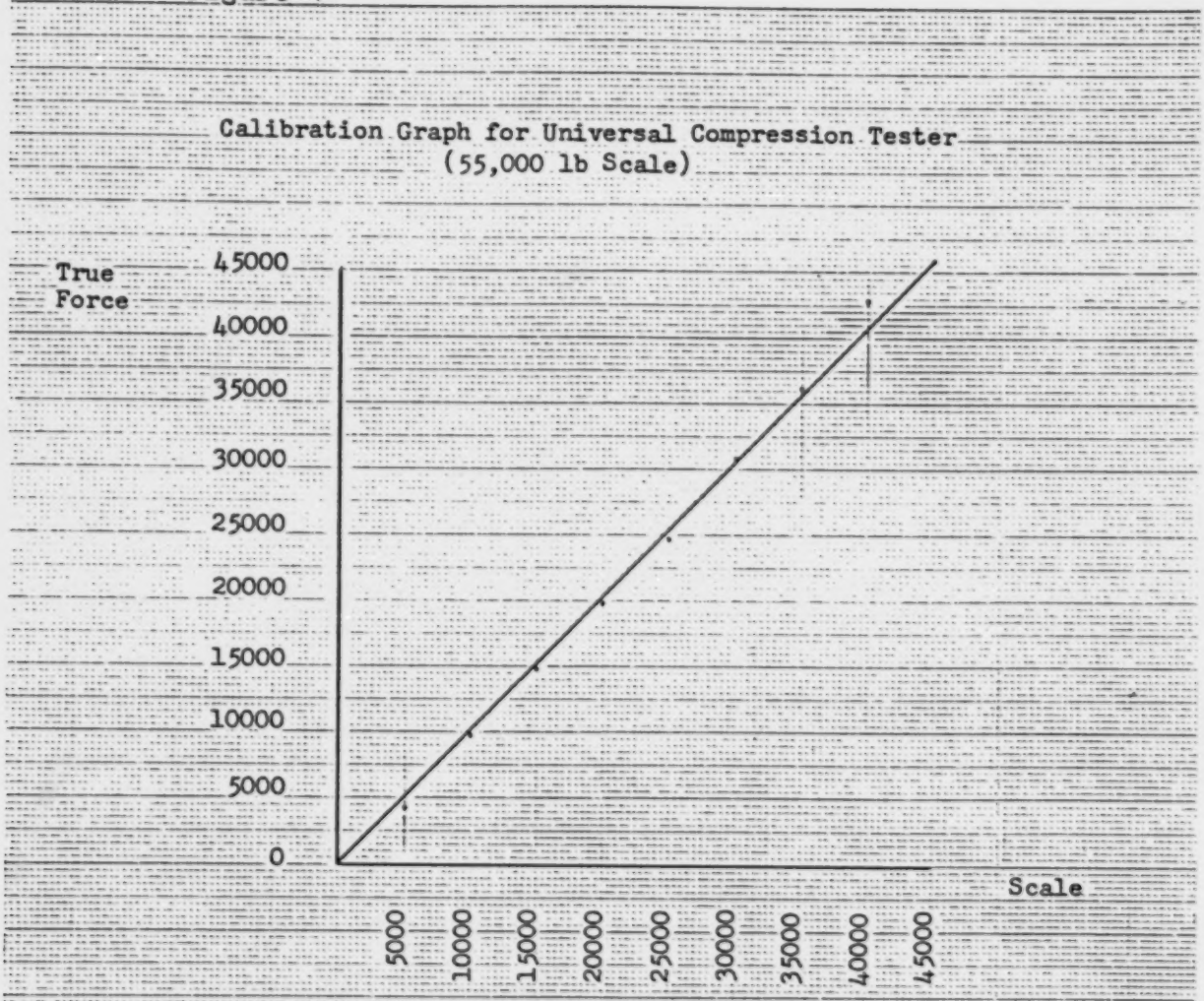
Figure 3



Scale	Mult x	True Force (lb)
2000	0.95315	1906.3
4000	0.98653	3946.1
6000	0.99058	5943.5
8000	0.98041	7843.3
10000	1.00333	10033.3
12000	1.00931	12111.7
14000	1.03133	14438.6
16000	1.02959	16473.5
18000	1.03667	18660.0

METRIC

Figure 4



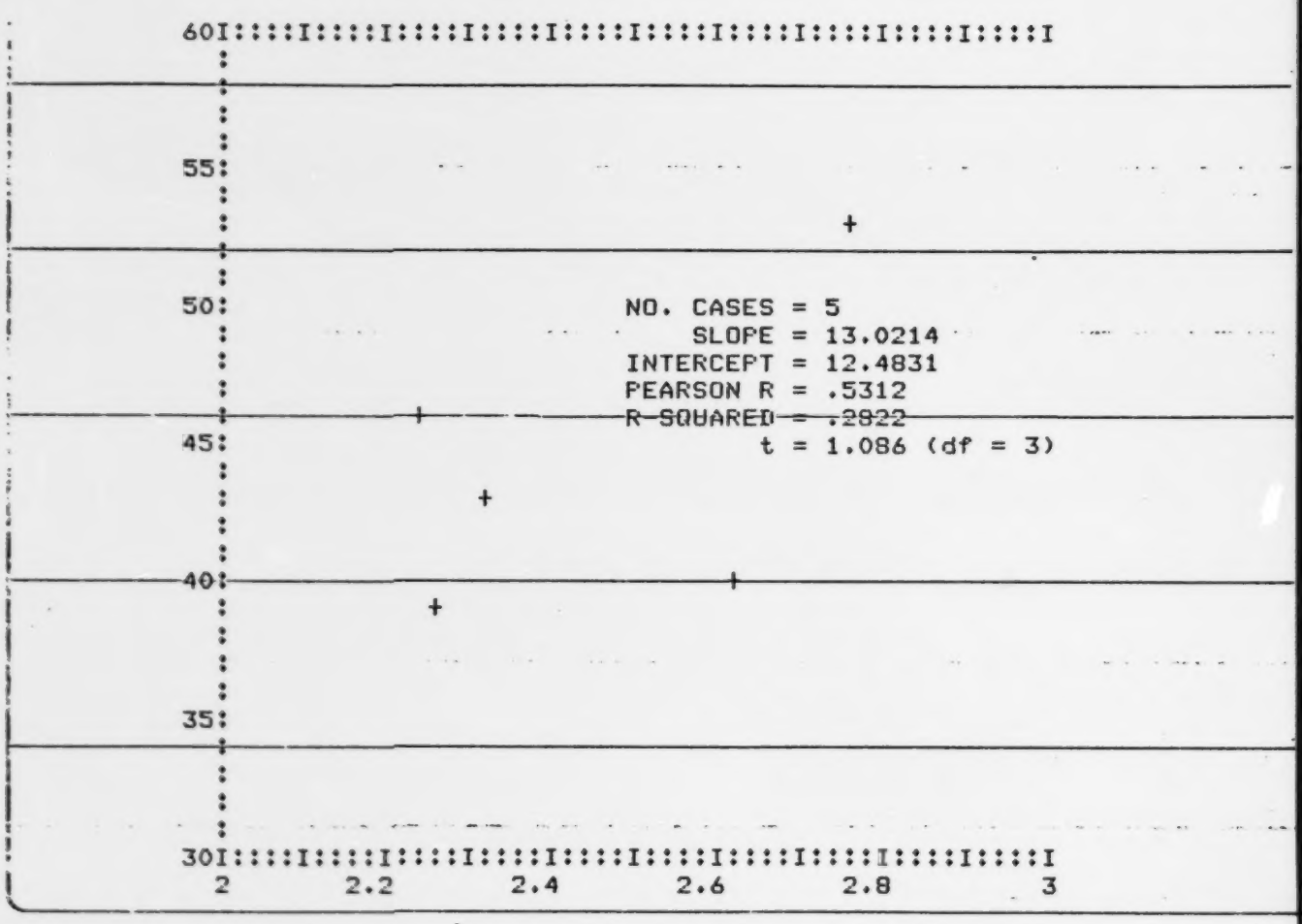
Scale	Mult x	True Force (lb)
5000	0.895	4473
10000	0.988	9881
15000	0.990	14854
20000	0.996	19919
25000	0.988	24716
30000	1.027	30821
35000	1.038	36340
40000	1.057	42294
45000	1.019	45860

METRIC

COARSE SANDSTONE COMPRESSED MEANS

FIGURE 5

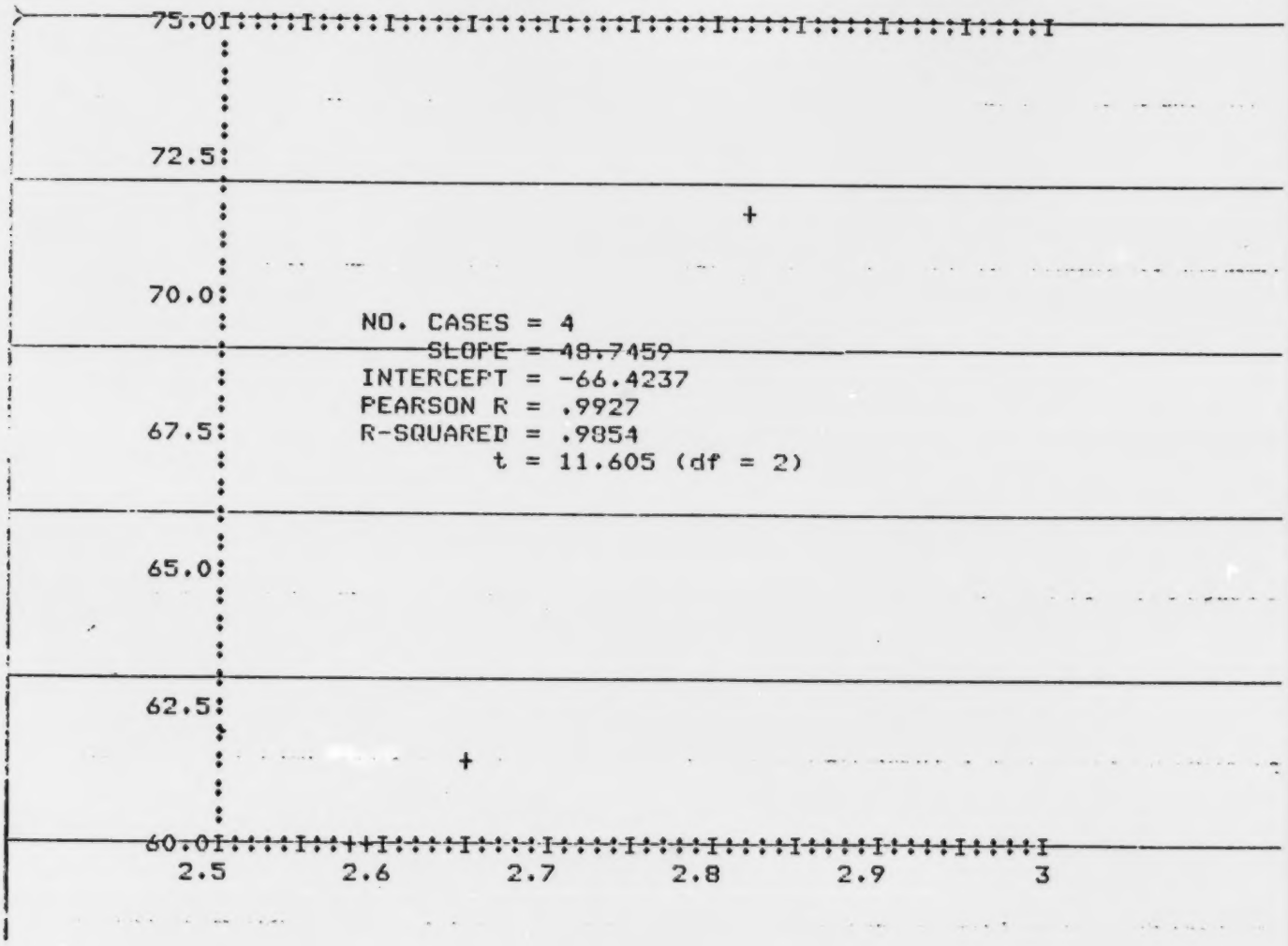
EQUATION I



MEDIUM SANDSTONE COMPRESSED MEANS

FIGURE 6

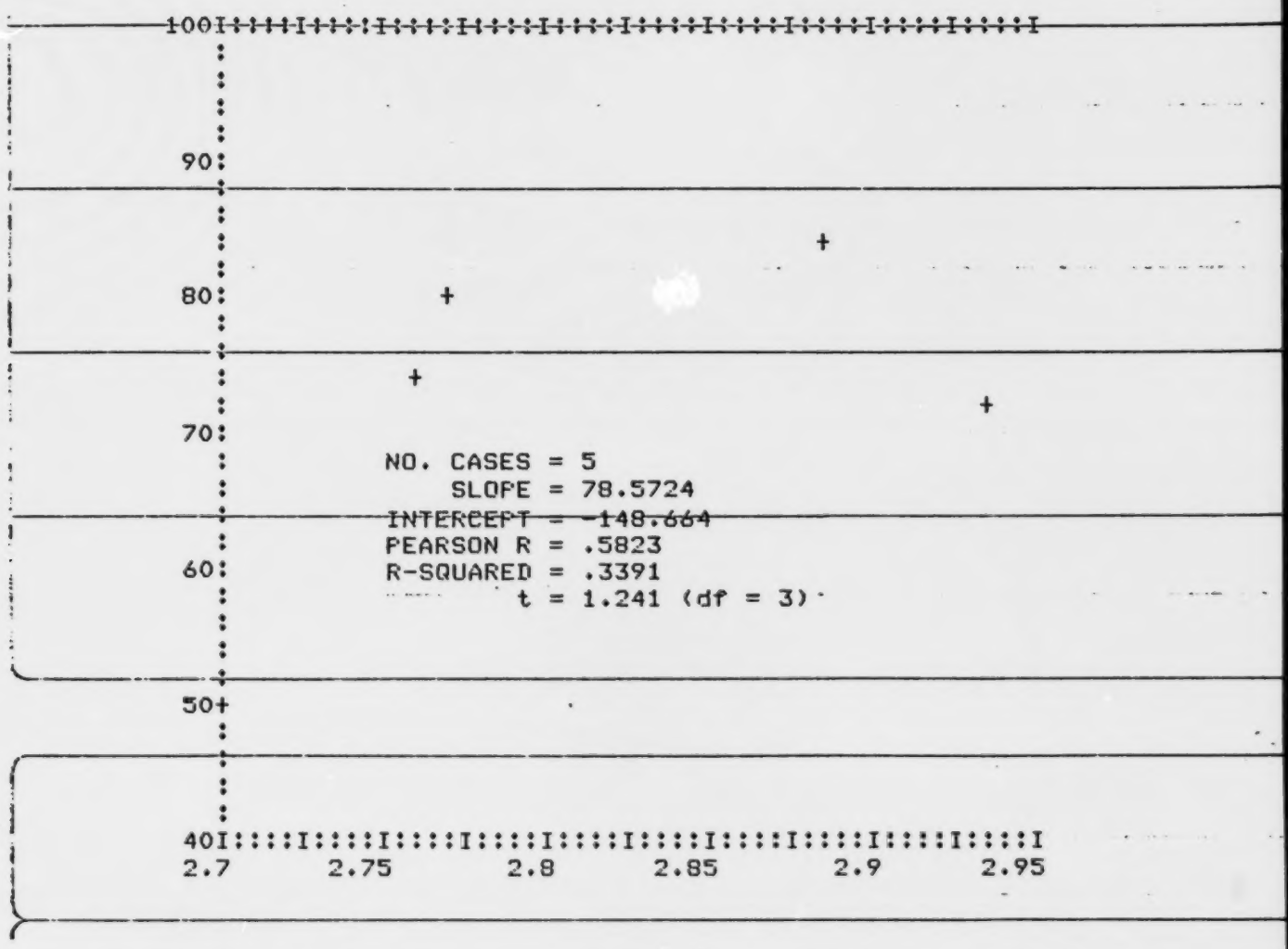
EQUATION 2



FINE SANDSTONE COMPRESSED MEANS

FIGURE 7

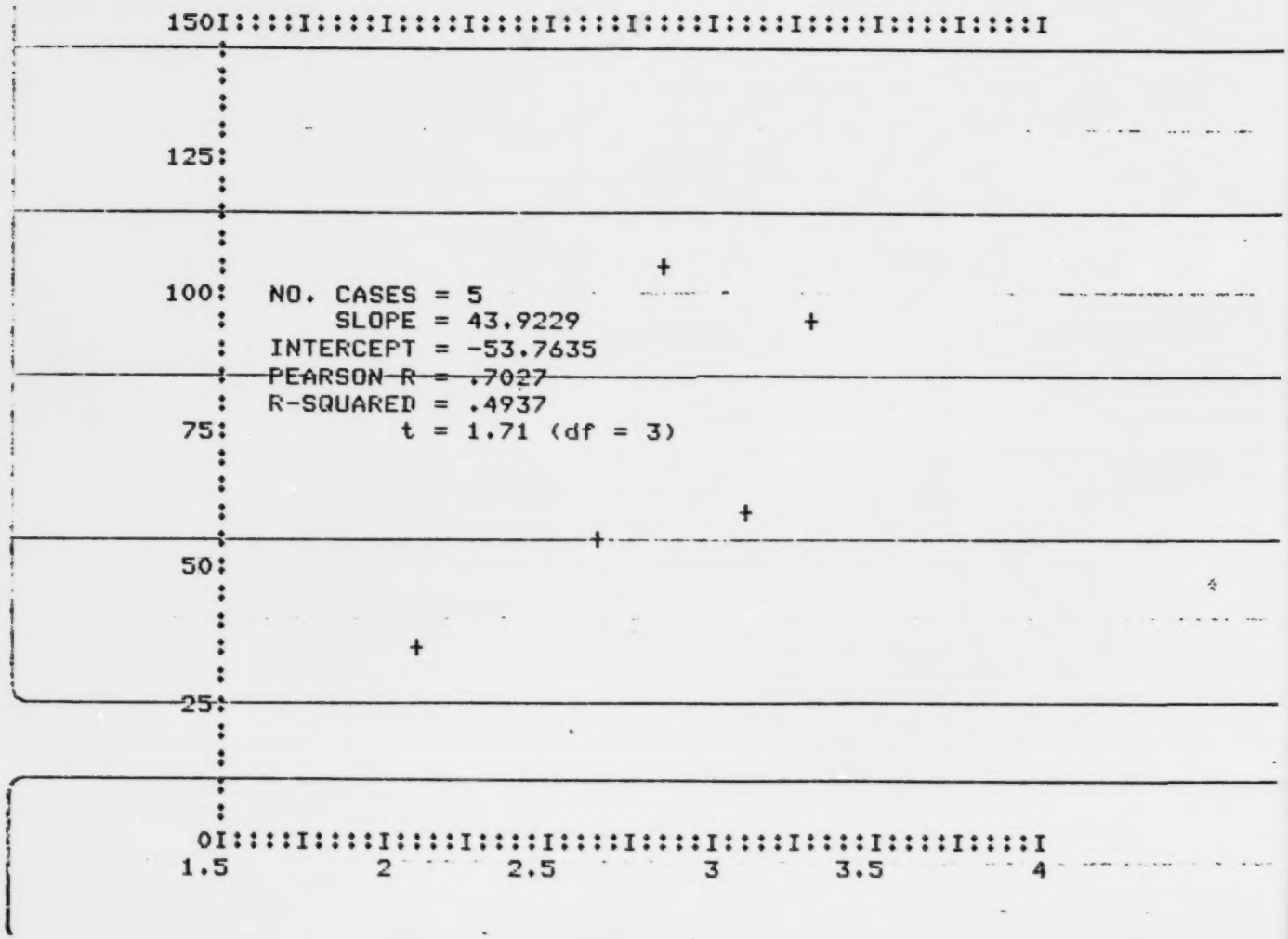
EQUATION 3



SILTSTONE COMPRESSED MEANS

FIGURE 8

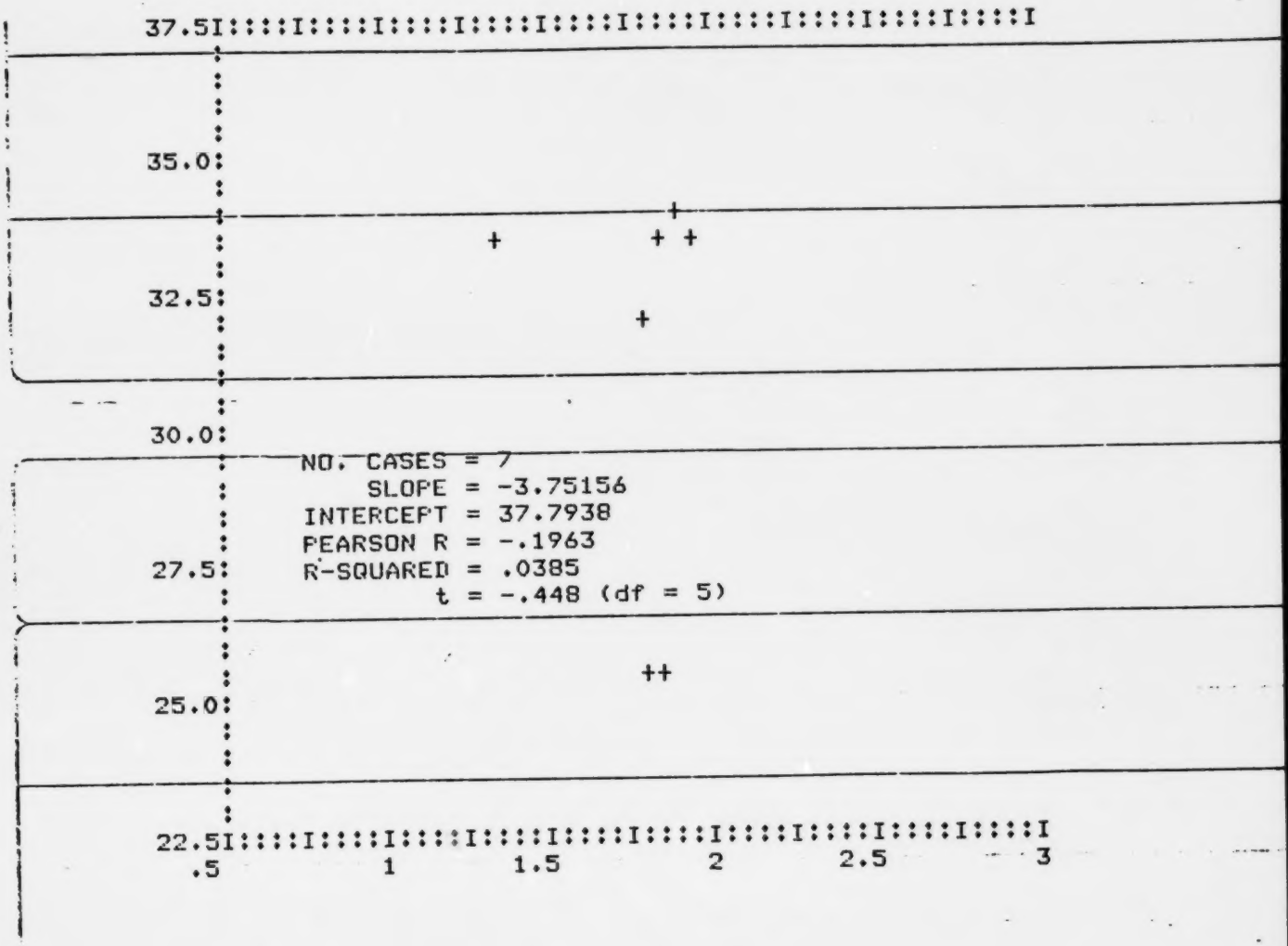
EQUATION 4



MUDSTONE COMPRESSED MEANS

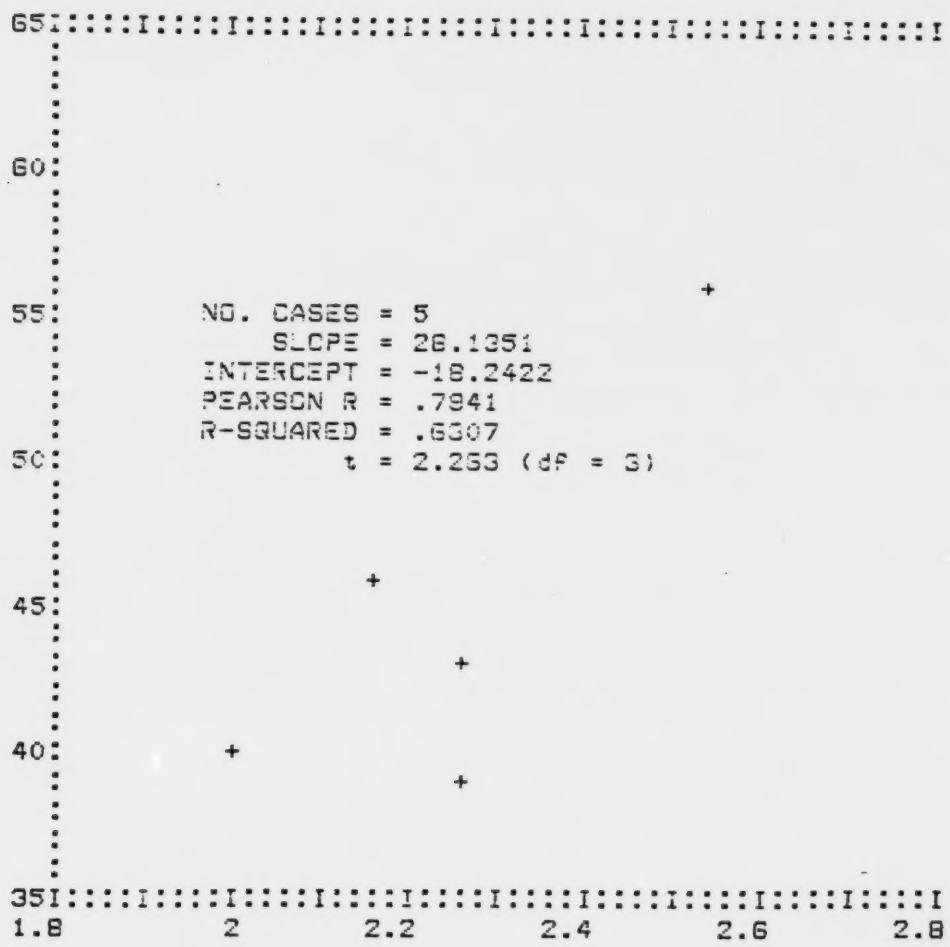
FIGURE 9

EQUATION 5



COARSE SANDSTONE COMPRESSED MEDIANS FIGURE 10

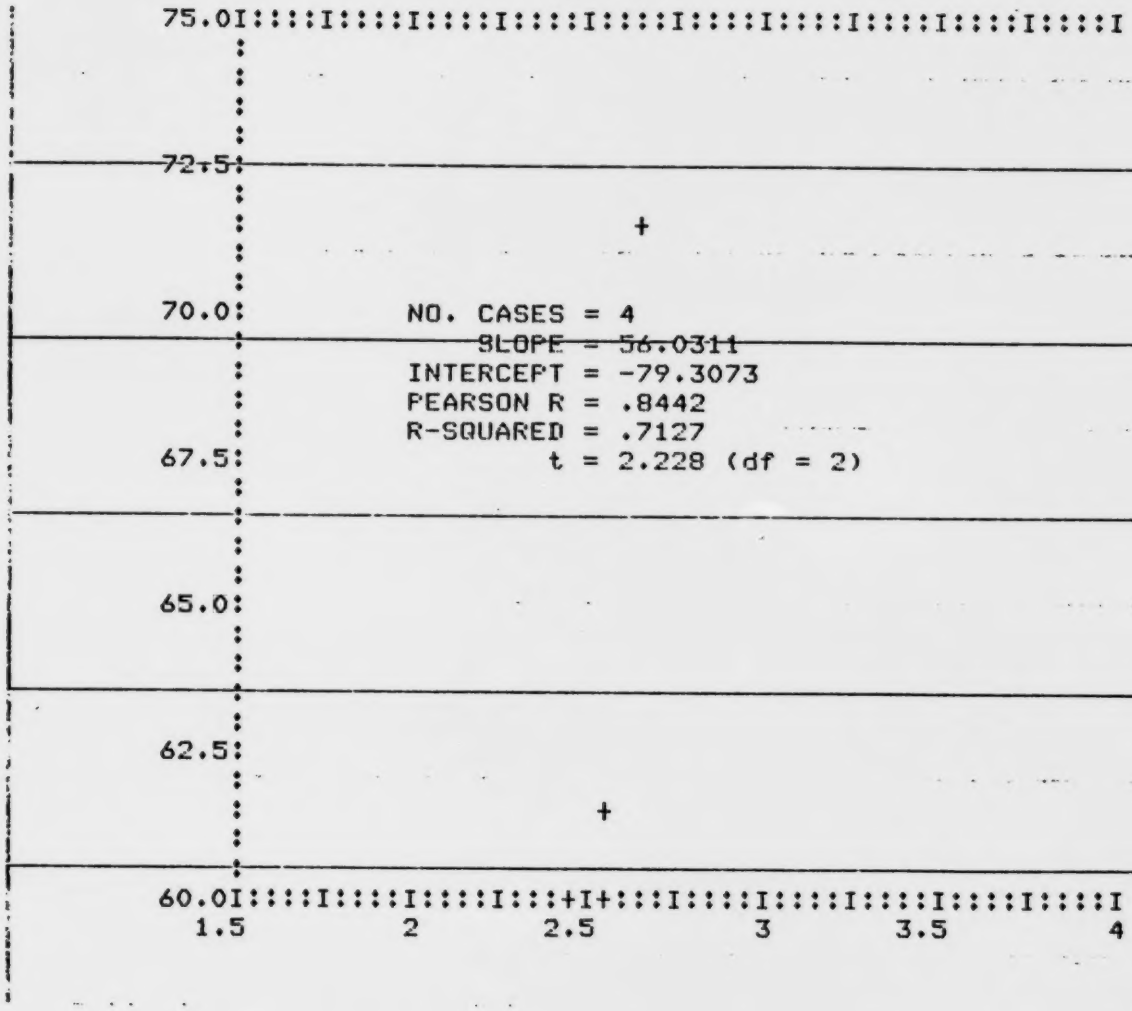
EQUATION 6



MEDIUM SANDSTONE COMPRESSED MEDIANS

FIGURE 11

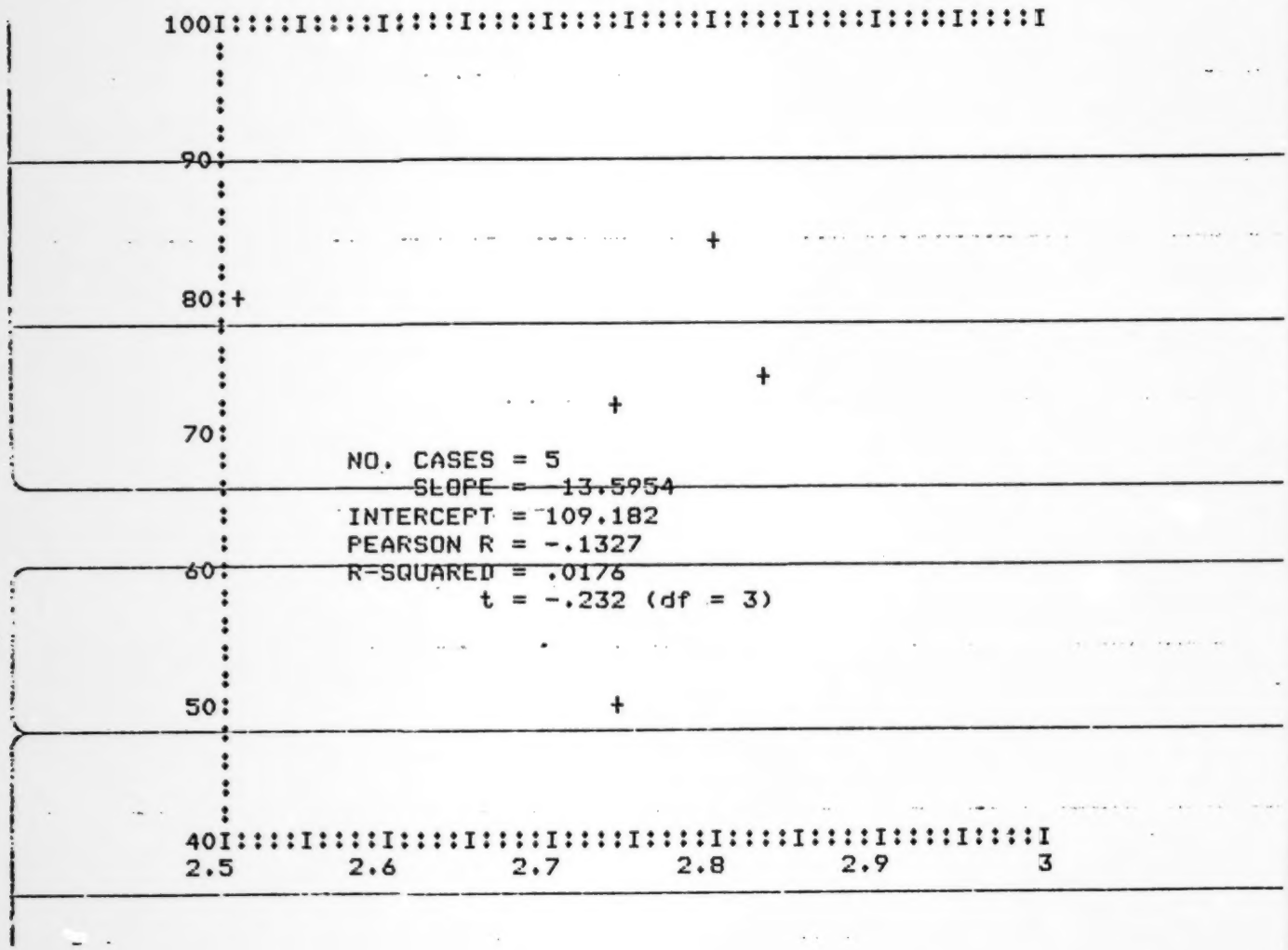
EQUATION 7



FINE SANDSTONE COMPRESSED MEDIANS

FIGURE 12

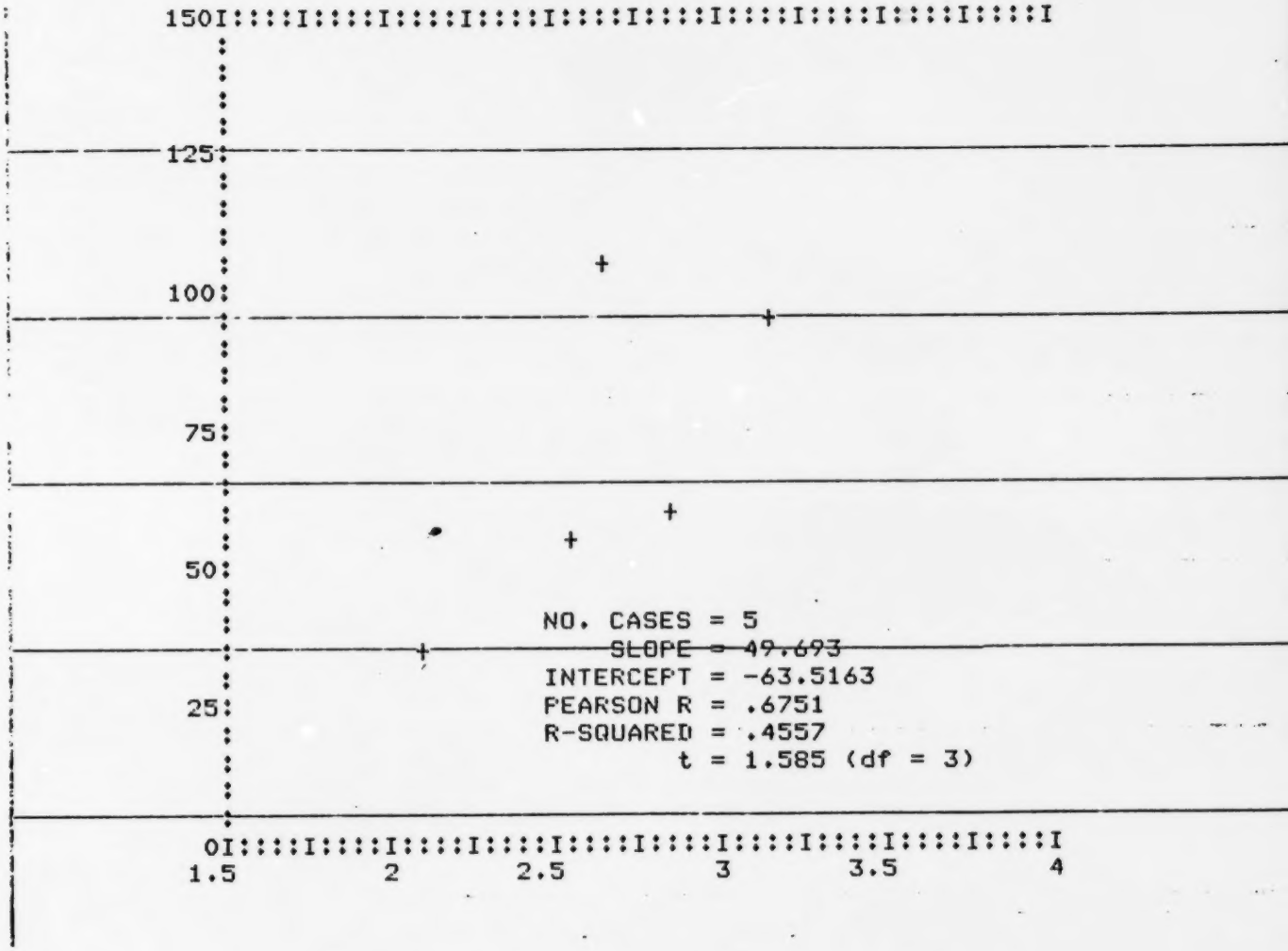
EQUATION 8



SILTSTONE COMPRESSED MEDIANS

FIGURE 13

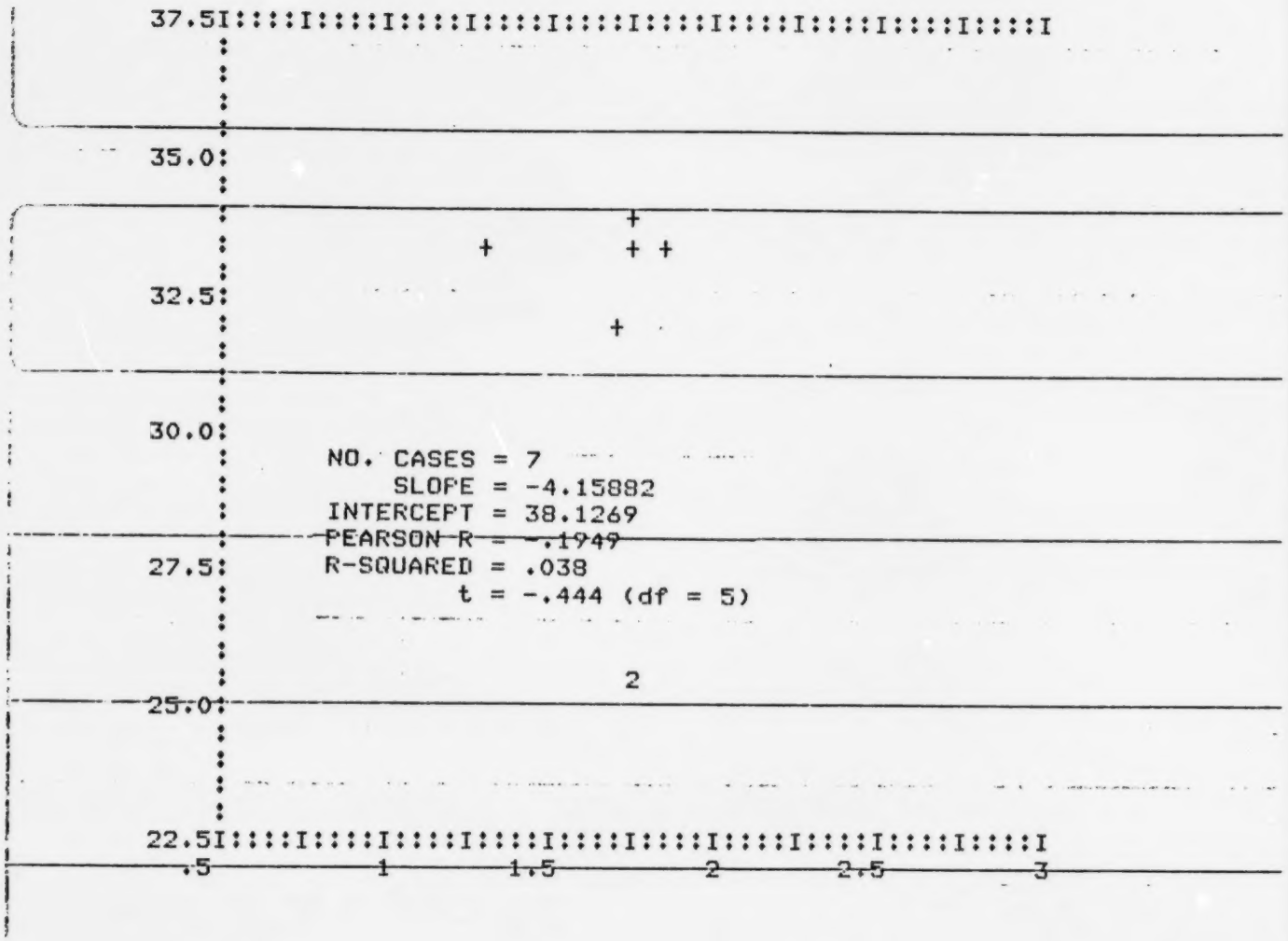
EQUATION 9



MUDSTONE COMPRESSED MEDIANS

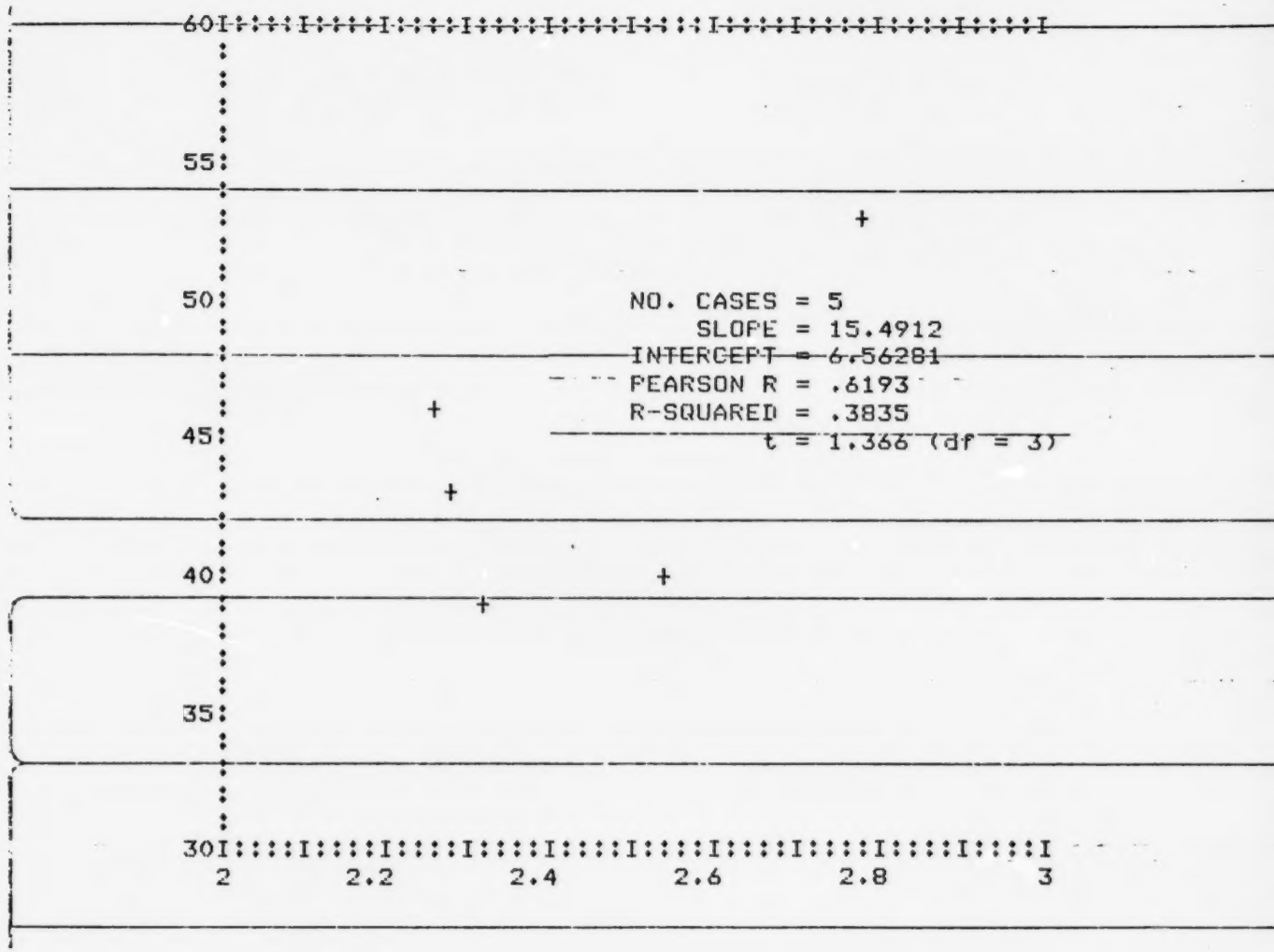
FIGURE 14

EQUATION 10



COARSE SANDSTONE OFFCUT MEANS FIGURE 15

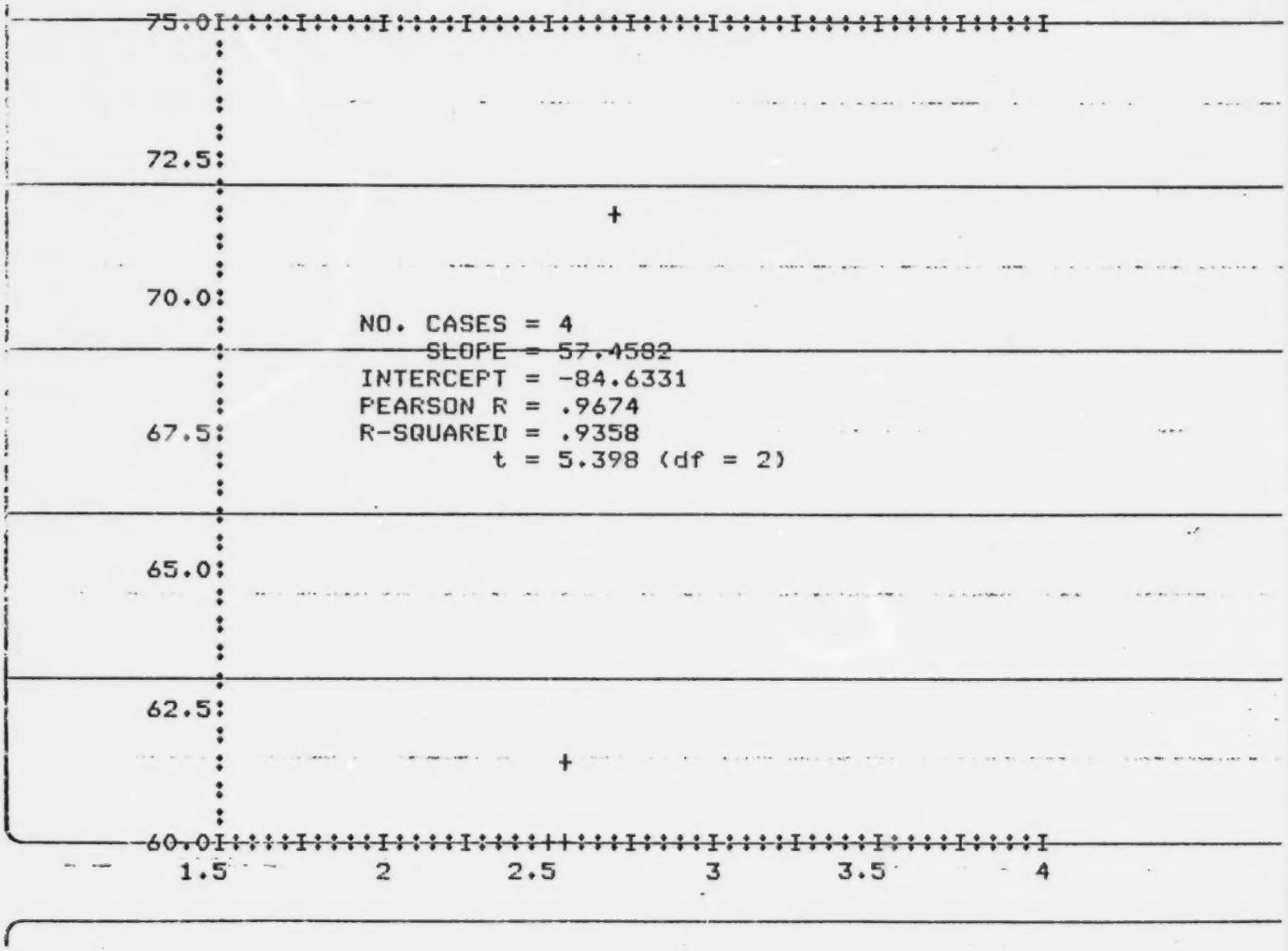
EQUATION 11



MEDIUM SANDSTONE OFFCUT MEANS

FIGURE 16

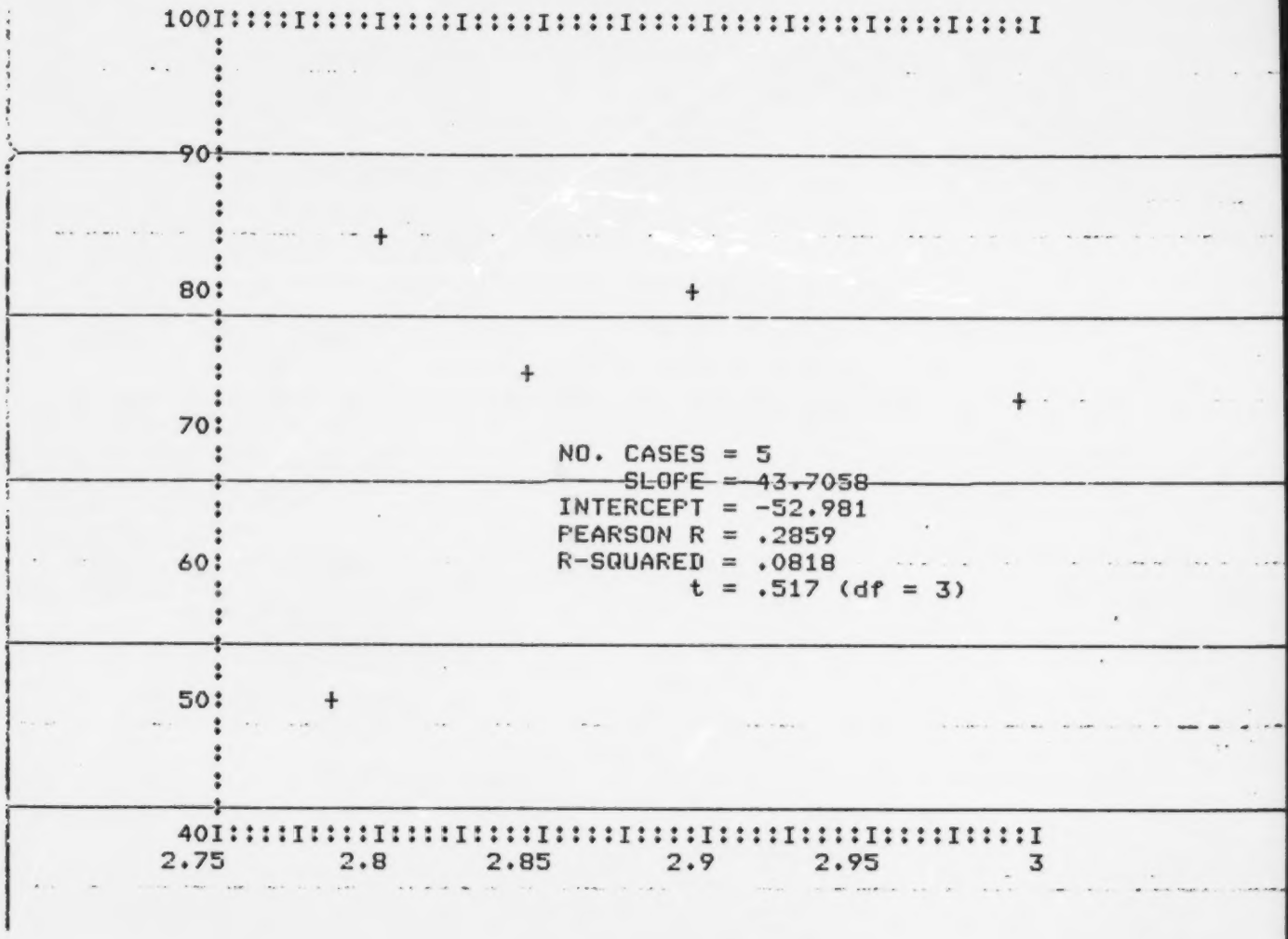
EQUATION 12



FINE SANDSTONE OFFCUT MEANS

FIGURE 17

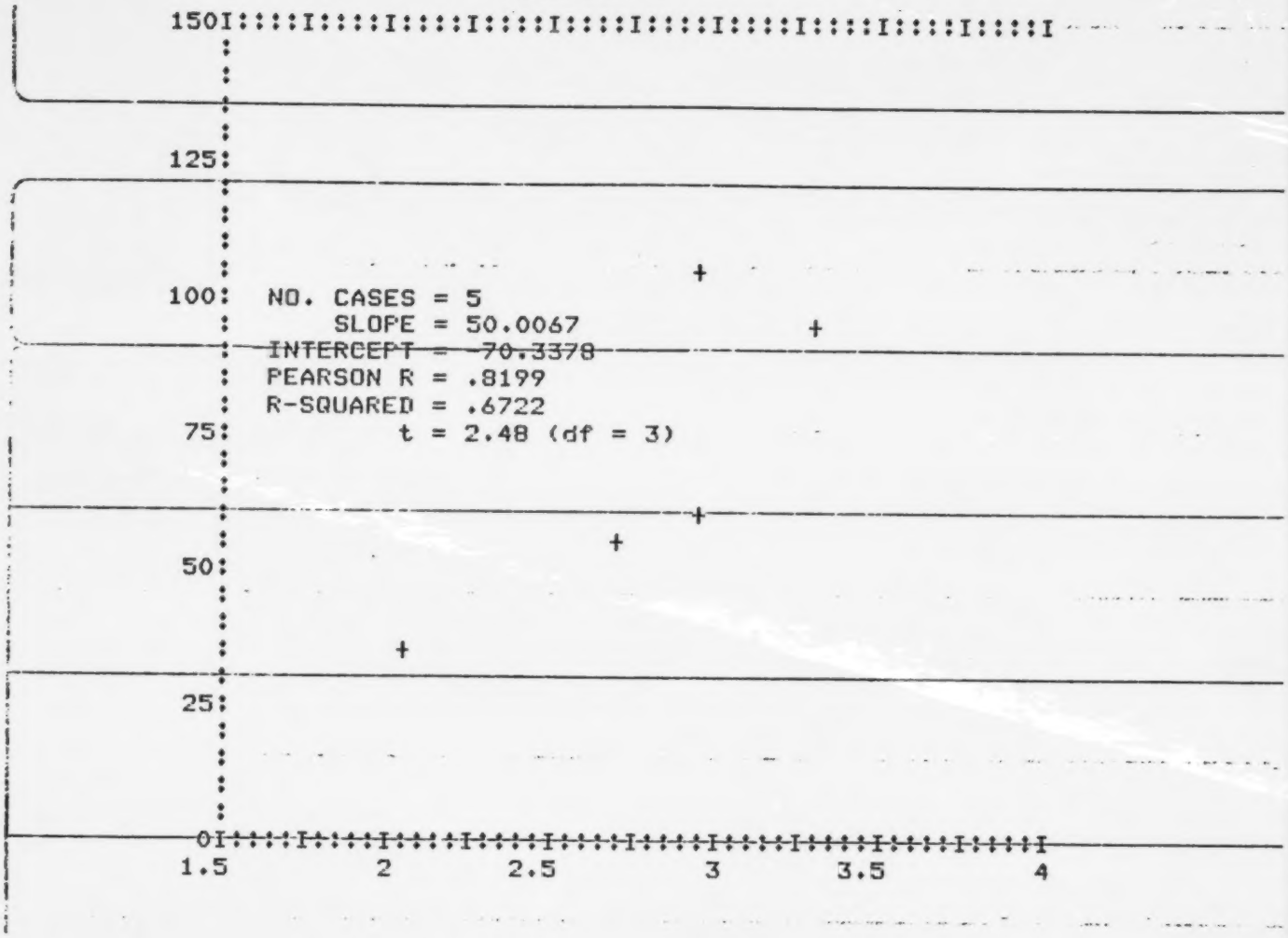
EQUATION 13



SILTSTONE OFFCUT MEANS

FIGURE 18

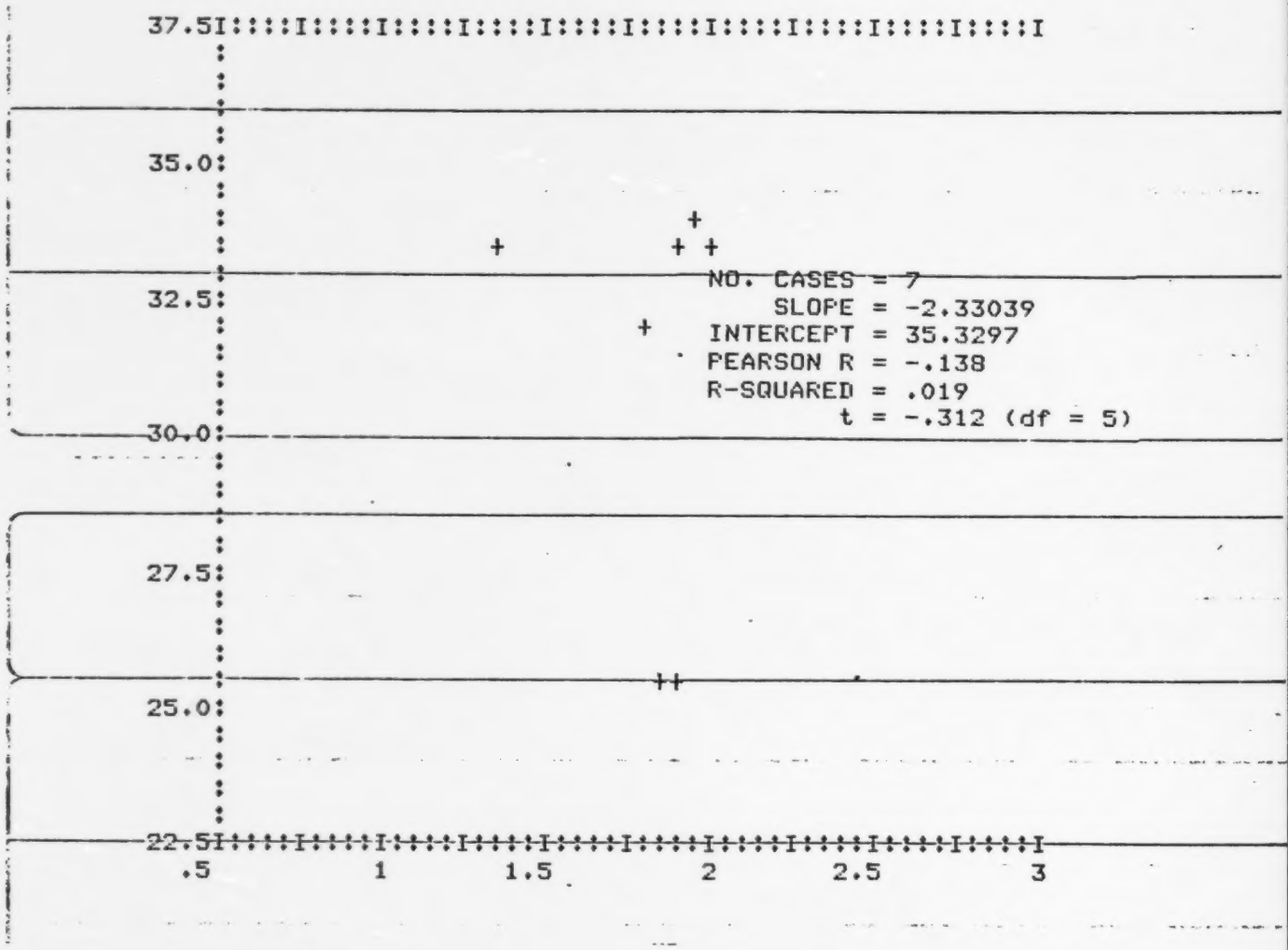
EQUATION 14



MUDSTONE OFFCUT MEANS

FIGURE 19

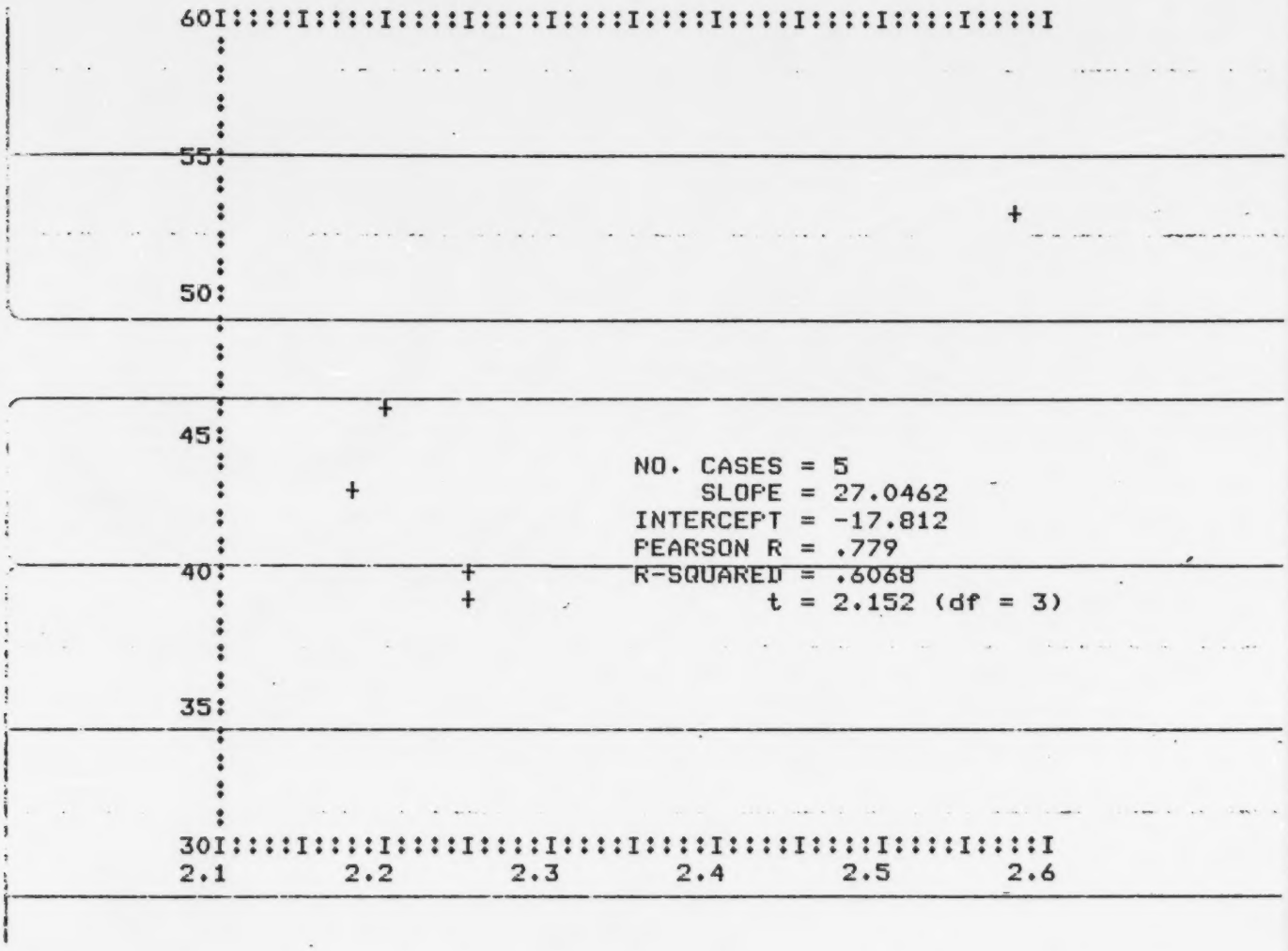
EQUATION 15



COARSE SANDSTONE OFFCUT MEDIANS

FIGURE 20

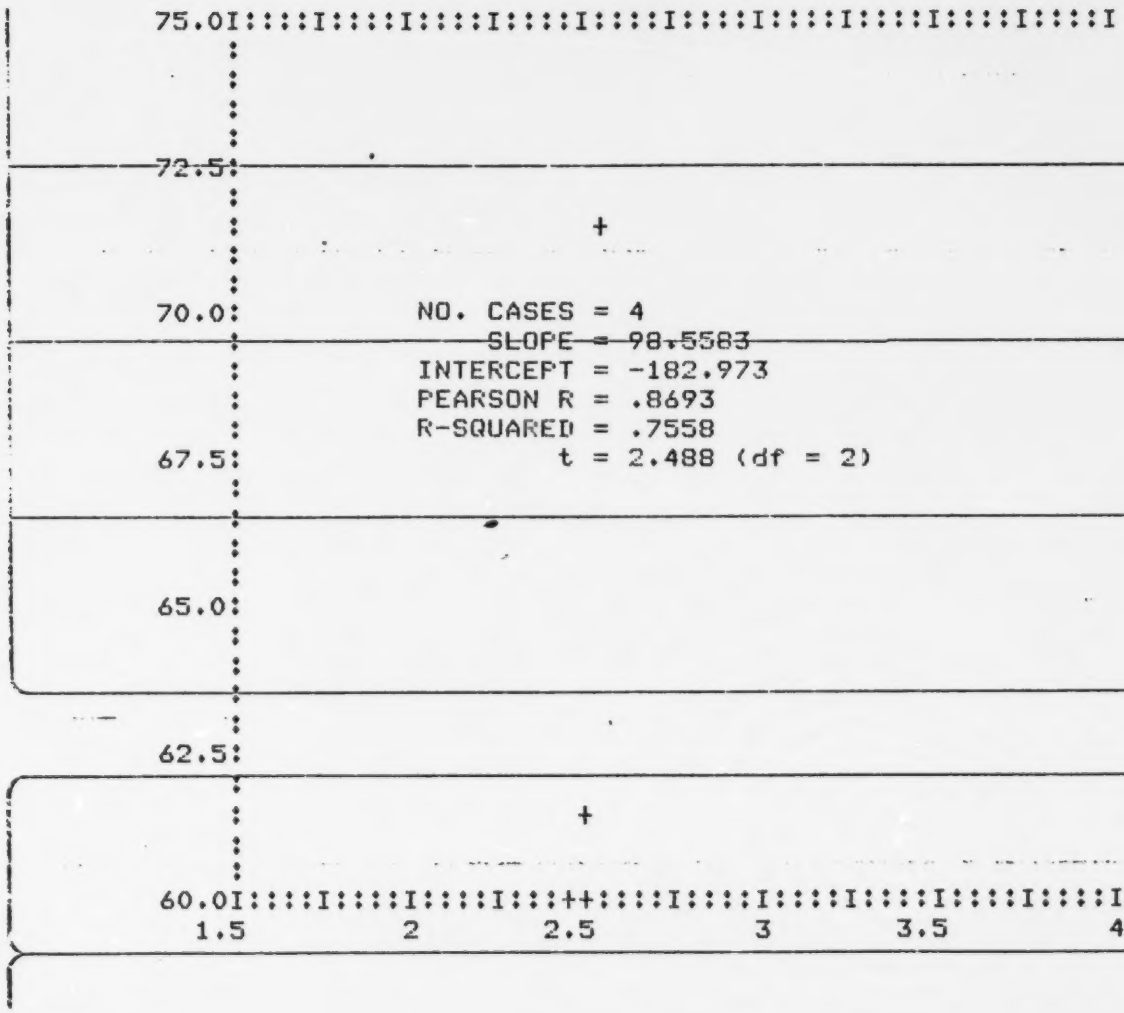
EQUATION 16



MEDIUM SANDSTONE OFFCUT MEDIANS

FIGURE 21

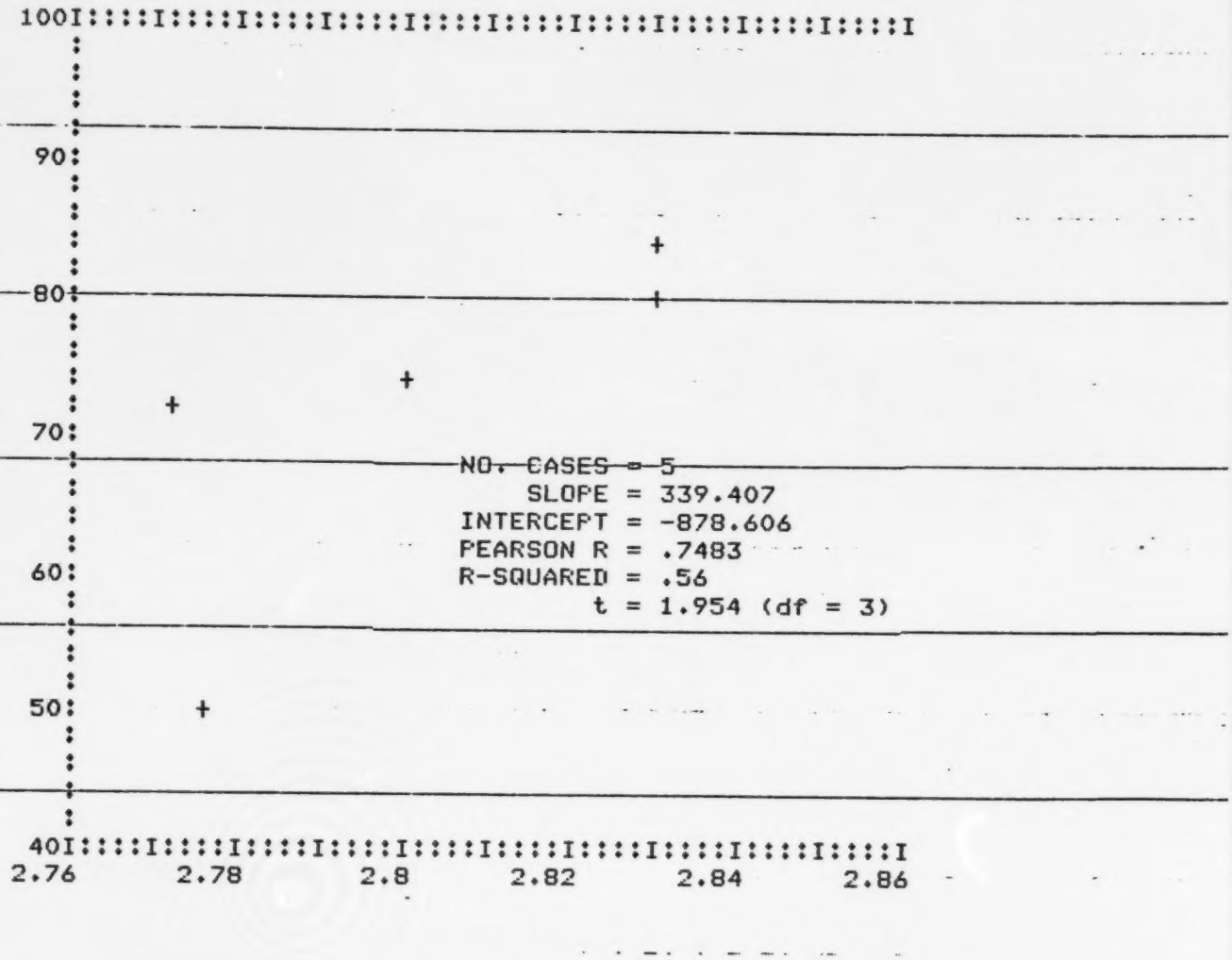
EQUATION 17



FINE SANDSTONE OFFCUT MEDIANS

FIGURE 22

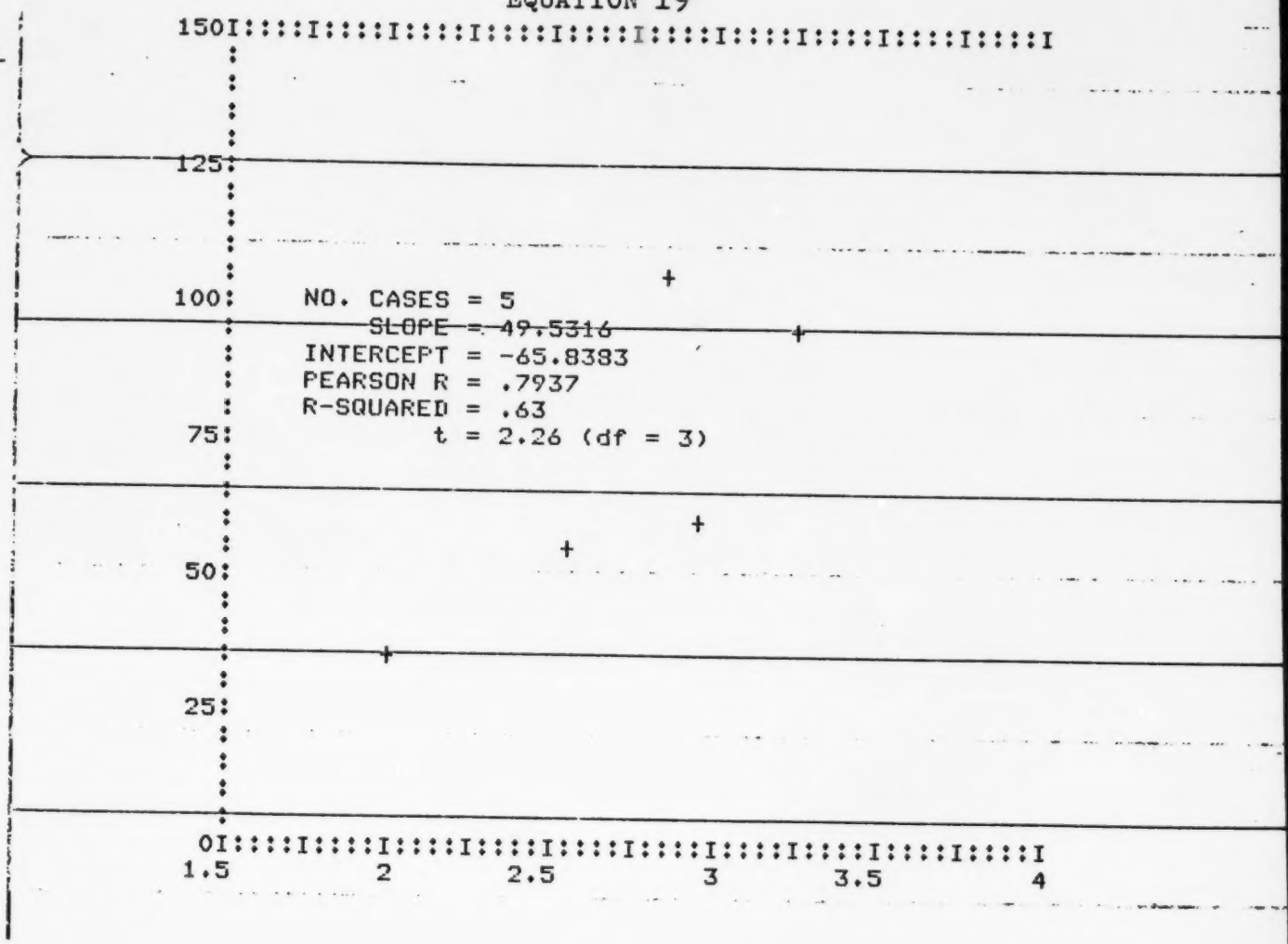
EQUATION 18



SILTSTONE OFFCUT MEDIANS

FIGURE 23

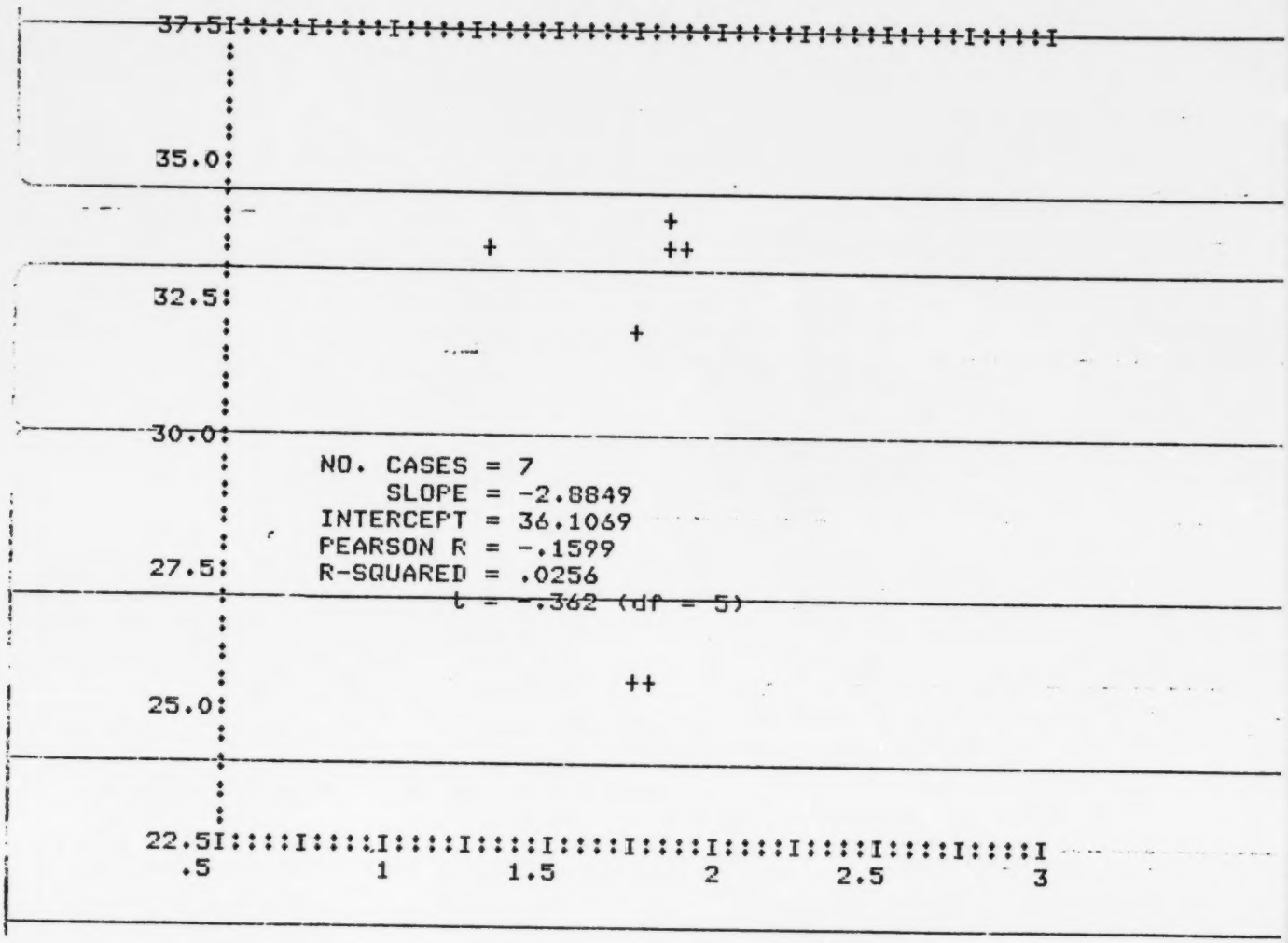
EQUATION 19



MUDSTONE OFFCUT MEDIANS

FIGURE 24

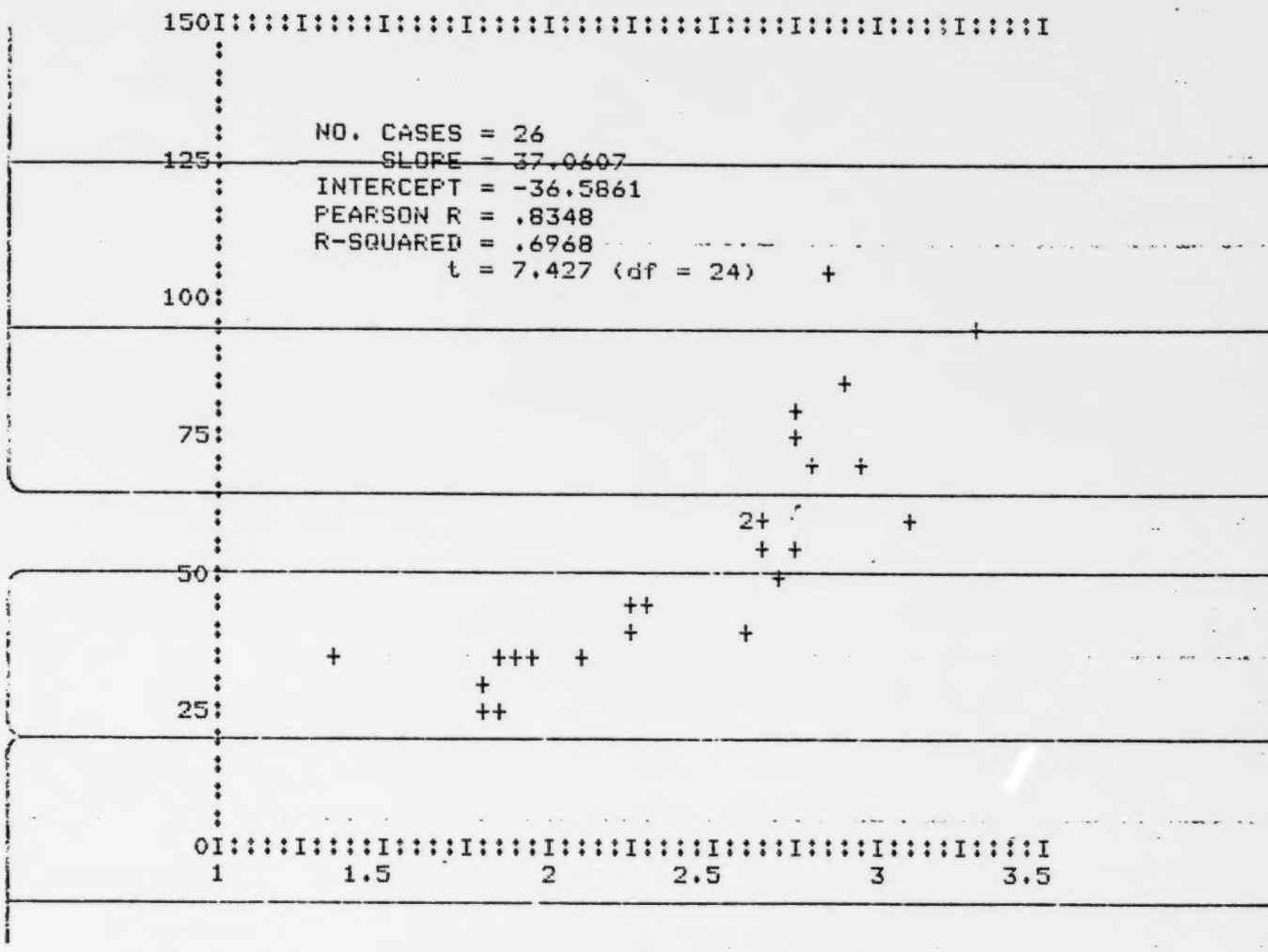
EQUATION 20



COMPRESSED MEANS

FIGURE 25

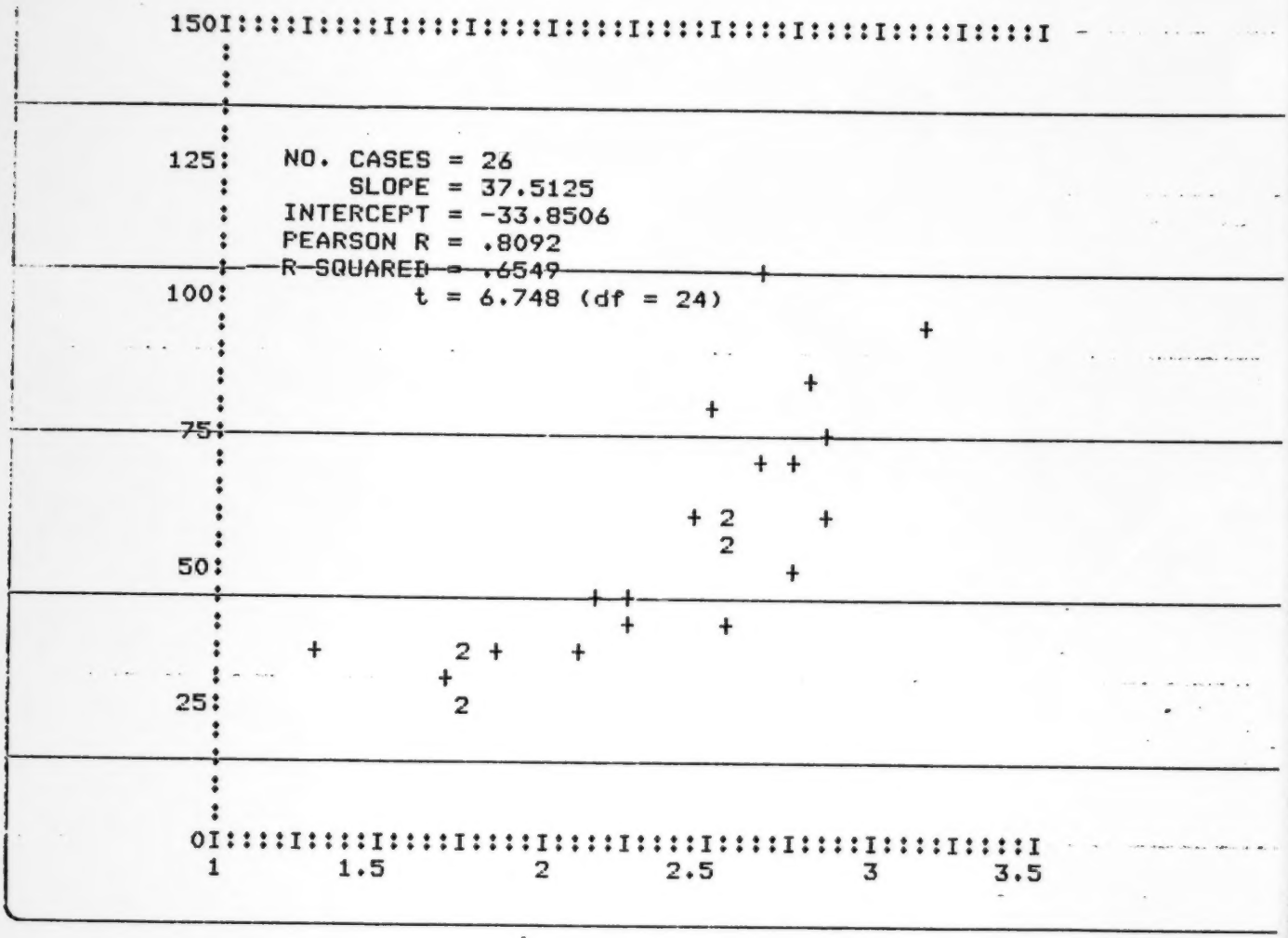
EQUATION 21



COMPRESSED MEDIANS

FIGURE 26

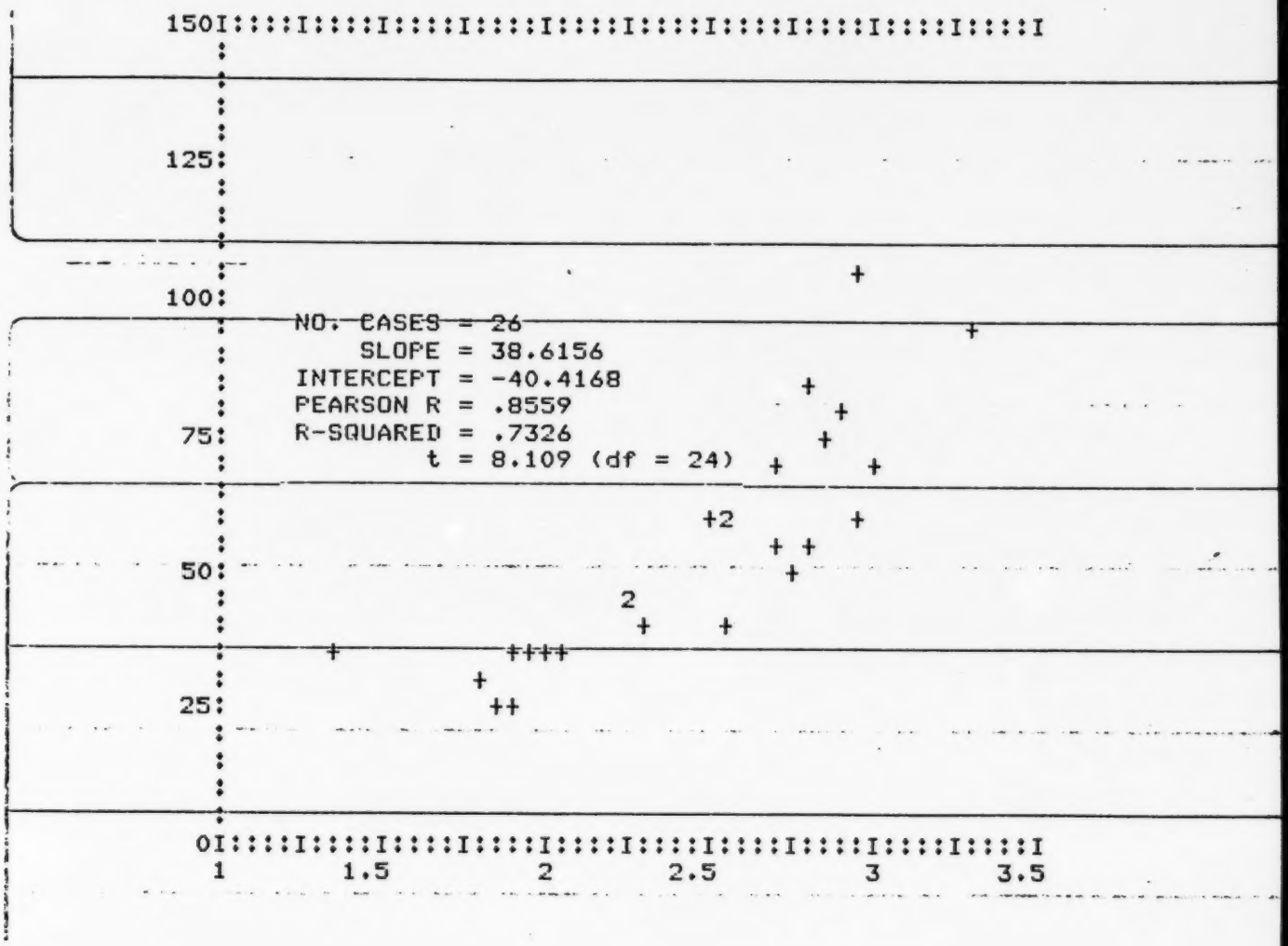
EQUATION 22



OFFCUT MEANS

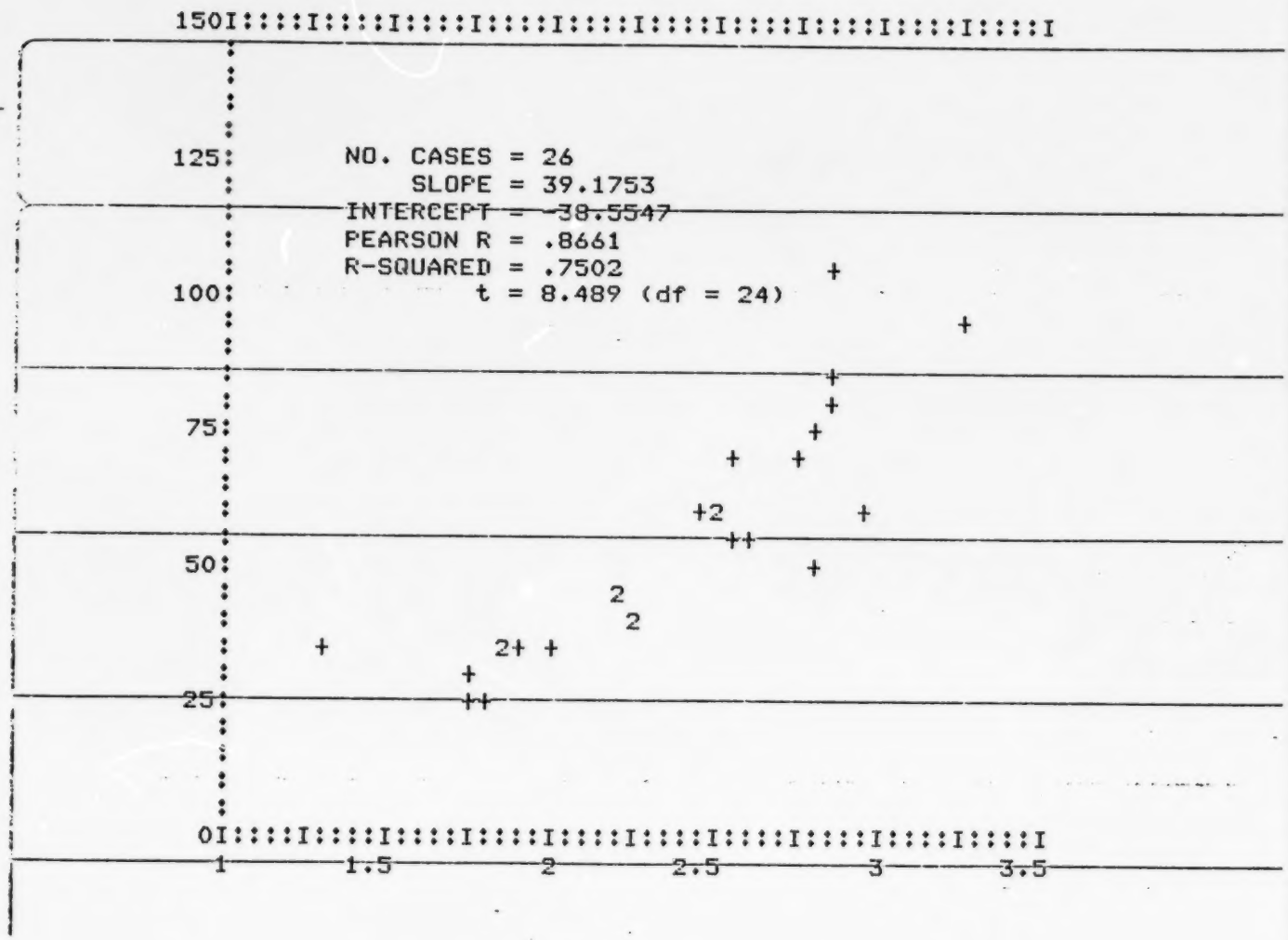
FIGURE 27

EQUATION 23



OFFCUT MEDIANS FIGURE 28

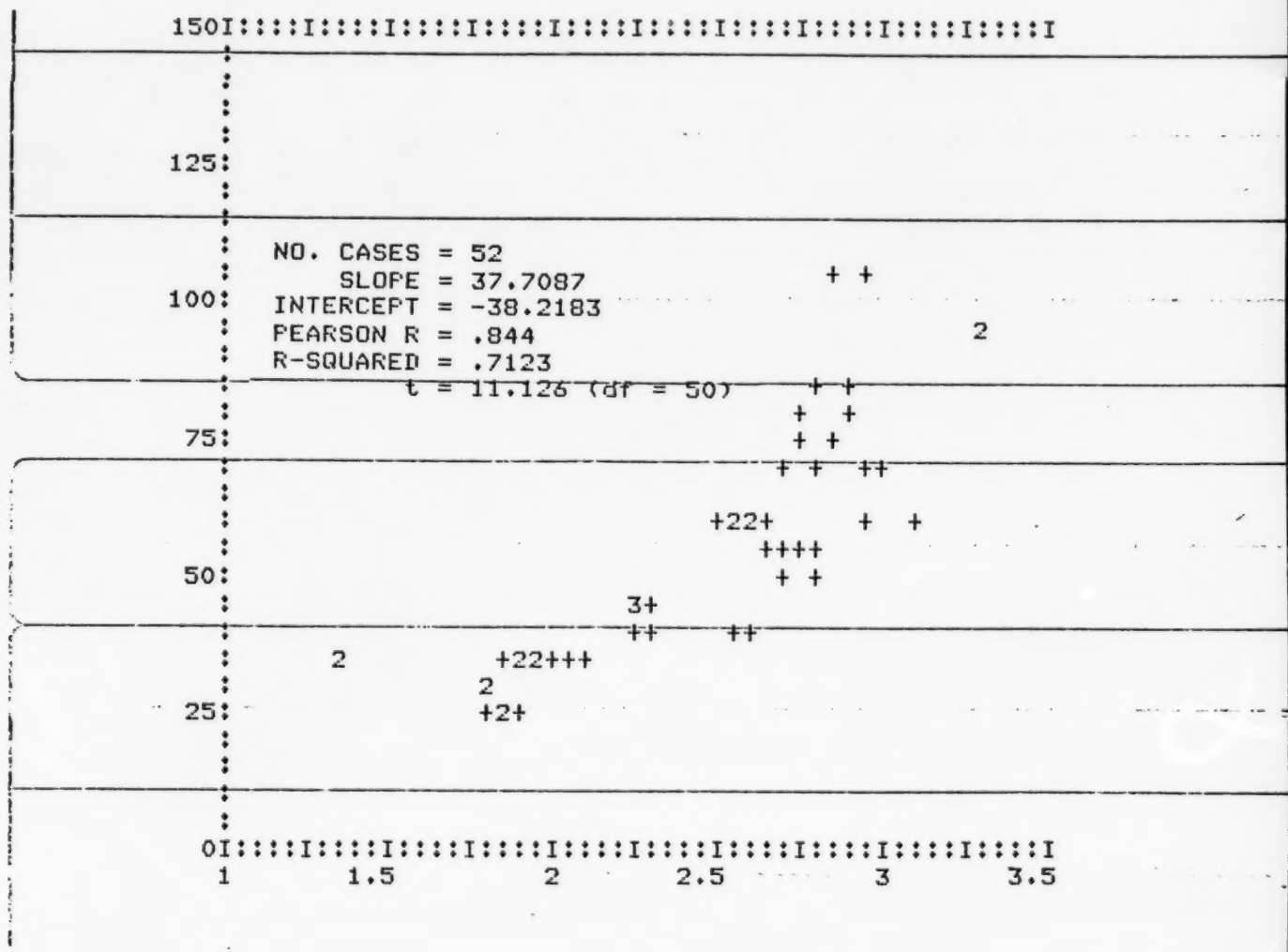
EQUATION 24



OVERALL MEANS

FIGURE 29

EQUATION 25



OVERALL MEDIANS

FIGURE 30

EQUATION 26